APPLYING LEAN TO THE F-15 MAINTENANCE PROCESS FOR THE ROYAL SAUDI AIR FORCE

THESIS

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Abstract

The ideas expressed in this research come from the researcher's experiences working in an F-15 maintenance squadron in the Royal Saudi Air Force. The research focuses on improving the F-15 maintenance process in the Royal Saudi Air Force's Maintenance Squadrons. The F-15 maintenance process currently requires too much time to make aircraft fully mission ready. Because the F-15 is the first line of Saudi Arabia's defense, it is essential that they be fully mission ready in the shortest time possible. That can be done by improving communication, reducing distances needed to move or transport anything during the F-15 maintenance process, and by efficient use of the available qualified workforces, tools and equipment. Consideration is given to applying an existing management technique to the Royal Saudi Air Force's F-15 Maintenance Squadrons. The selected technique is the "Lean" management approach. The research suggests that Lean can help and improve F-15 maintenance process in the Royal Saudi Air Force for several reasons. One of the most important reasons is Lean will get rid of waste and can measure the process improvement.

To my Parents.

To my Family.

To my country.

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Alamri, Mohammad

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APPLYING LEAN TO THE F-15 MAINTENANCE PROCESS FOR THE ROYAL SAUDI AIR FORCE

I. Introduction

Importance of Saudi Arabia

The Kingdom of Saudi Arabia is critically situated in today's world. Saudi Arabia is one of the important countries in the Middle East. Its large oil production makes it crucial to many nations throughout the world. It is the host and protector for many religious sanctities, cultural and historical artifacts. The Kingdom of Saudi Arabia provides a defense against any aggressive intentions. Though the Kingdom of Saudi Arabia has peaceful intention, it maintains an air force to defend these trusts. One of the most important weapons that the Kingdom of Saudi Arabia has is the F-15 aircraft. They are one of the main weapons that the Royal Saudi Air Force uses to defend itself from any air breach. F-15 aircraft should be fully mission ready most of the time. This can be done by performing a good maintenance. The current F-15 maintenance process requires excessive time to make the aircraft fully mission ready. This reduces the aircraft's potential as a rapid response system.

The Problem

From the researcher's experiences working in an F-15 maintenance squadron, which is subordinated under the logistic wing, a lot of time and resources are consistently spent maintaining the F-15 aircraft to full mission readiness. This is not happening because of lack of knowledge, manpower, tools and equipment. This happens because the current maintenance process takes time and that conflict with the mission of the F-15 aircraft, which is to be ready to react fast when needed. Maintenance is main factor which keep F-15 aircraft flying. Having a good maintenance process which can perform in shorter time would be beneficial for Royal Saudi Air Force. This thesis present lean as a solution to improve the maintenance process since lean principle suggest that any process can be improved. So why does the F-15 maintenance process consume time and why this thesis choose lean? This chapter will explain in detail why lean is the way and why the F-15 maintenance process consume time that can be reduced.

The Saudi Arabia Air Force has 4 models of F-15:

- D model, which has two seats, is mainly used for training purposes, and is around 30 years old.
- C model, which has one seat and is as old as the D model.
- S model, which has two seats and is around 17 years old.
- SE model, which has two seats and is considered new.

The C and D models are old enough to return after each flight with maintenance problems. The S model has fewer maintenance demands but takes the same preparation

time because of the maintenance process. This process requires a lot of time spend in maintenance after each flight mission.

Why Maintenance Take That Long?

Each aircraft has a daily mission schedule which may require multiple flights. At a given point of time all of the aircraft are fully mission ready. However, as the days elapse, the number of aircraft that are fully mission ready starts to fluctuate and the number of available mission ready aircraft decreases. The time needed to fix all of the aircraft increases resulting in extended maintenance times, which may continue into the next day. Within a few days, extra work is required to complete the required maintenance to bring all aircraft to flight status.

The time spent in F-15 maintenance process preparing the aircraft makes the aircraft useless during that period of time. There is no benefit from defense aircraft which are broken most of the day.

It is possible that these issues combine and result in causing this state of affairs. Consider distance for example. The distance between aircraft Aviation Ground Equipment and aircraft shelters makes the time spent in moving from/to shelters an issue. That time increases as distances become greater between shelters within the Aircraft Generation Flight or First Line. When requesting assistance from other shops and departments the one way distance will take more than 15 minutes with a sedan car and much more than that with heavy trucks, vans and specialized vehicle types. So the

transportation itself increases the time in the F-15 maintenance process. It is one of causes of the problem.

Repeating other departments' work also increase process time. For example, consider the material office in the F-15 Aircraft Generation Flight. This office mediates between the Maintenance Squadron and the Supply Squadron. Some parts are available but because of the material office's process the part will not come as soon as possible. In some cases, like changing shifts between material staff or supply staff, the delay could be more than four hours.

Even searching for the information amongst the various departments or shops delays the work. Shift changes and having many people independently receiving the information makes the information easy to lose. Add to that, in some cases, it is often difficult to reach some people or departments because there is no central point of contact or inefficient use of the office lines, radios or even internal networks.

The different goals and priorities for each department or shop lead to a lack of cooperation between them. Because of this the main goal for the Royal Saudi Air Force may be lost in the process. One of the most important goals for the Royal Saudi Air Force is the readiness of its aircraft. Through such loose of focus on the final purpose of the maintenance process, one department can make the Royal Saudi Air Force lose an aircraft for a day by mistakes in documentation paper or because they have their own rules and they need to do the job their own way.

All of these issues and impediments lead to the F-15 maintenance process requiring a lot of time and result in crews working late or on weekends. It is obvious, but important to notice, that these issues have nothing to do with the tools that been used to maintain the aircraft or the quality of the maintenance performed. They are management problems which can be avoided. The consequences of these issues lead to an increase in the work and pressure on the maintenance squadron workers and employees which could affect their morale. One of the main reasons for people to join the Air Force is their feeling of responsibility to their country, to defend what they love and believe. But with continually increasing load and pressure, workers become frustrated and may decide to leave their job to find another job with less stress. This may also lead to carelessness or weakness at critical moments. Such conditions also lead workers in the maintenance squadron to look for other jobs that pay better or pay overtime.

Shortening work hours by using the Lean techniques may result in reducing the stress that workers feel. Another important affect for reducing the work hours is increasing readiness time for the aircraft which is one of the Royal Saudi Air Force main goals. That makes the aircraft effective for their main purpose and ready most of the time. This also gives the Air Force the confidence in the weapons it has and reduces the 24 hours daily work load to two shifts only.

Why Lean?

From the above, management development is what the F-15 maintenance squadron needs to improve the maintenance process. This is the issue that has been discussed and is related to the management process. Current management regulations are

due to the previous commanders who decided at that time that their way was suitable. Indeed it was suitable 30 years ago when the aircraft were new and there was little maintenance work on them. It is now necessary to change the management styles that have been used for more than 30 years. Some previous commanders succeeded in improving the system by changing small decisions related to management. Based on that and on the aircraft age condition, the researcher concludes it is time to get rid of some obstacles and use new management techniques to resolve the overhaul system problem. Lean can contribute to speeding up the F-15 maintenance process. After investigating different management methods the researcher believes that Lean is the suitable choice to develop the F-15 maintenance process.

What is lean?

Lean is a management method that was developed by the Toyota Company after World War II to improve its productivity and quality. Lean's main idea is to eliminate the waste. Toyota's competitors in Japan and in other countries have adopted Lean to try to stay competitive with Toyota. Lean works for a lot of companies who use it. Lean becomes a solution for the factories and companies who are in trouble and need a quick solution.

Why Use Lean in The Air Force?

Lean has ways and techniques for solving and finding solutions. Lean does not depend on one man's decisions. Lean is a management method based on rules and a

system. Lean needs analysis and understanding before applying it. In addition, it is not hard to do. It is well understood and it is so rational.

The thing that makes Lean suitable for the Royal Saudi Air Force is the numerous steps and time spends in the current process. These steps and time make it easy to identify how to apply Lean to the Royal Saudi Air Force. Even if the Air Force is not a company and has no competitors, Lean addresses the needs of its maintenance processes. Another reason to use Lean is that the aerospace industry has started to use it and the Royal Saudi Air Force is a customer of companies in that aerospace industry. The Boeing Company, who built the F-15, is starting to use Lean in manufacturing new aircraft and in maintaining them. All of this shows why Lean is chosen to improve the F-15 maintenance process.

One reason that cannot be neglected is the usage of Lean by other Air Forces around the world. The US Air Force developed a system called AFSO21 which is about applying Lean in the US Air Force. The US Air Force even developed a manual for AFSO21 to show each department how it should use Lean to work. The existence of AFSO21 and the application of Lean in US Air Force make seeing the improvement due to Lean in a similar air force environment easier. This is especially true, if that air force is the world's number one Air Force. It should be remembered that most of the Royal Saudi Air Force systems and regulations were adopted from the United State Air Force. That should make AFSO21 one of the most important referenced documents mentioned in this research.

Problem Statement

The purpose of this research is to investigate ways to improve the efficiency of the F-15 maintenance process in the Royal Saudi Air Force (RSAF). It has been observed that on a regular basis, overtime is required to get F-15 aircraft mission ready. This could lead to decreased morale within the maintenance personnel due to an increased workload. This problem is also contributing to reduced F-15 readiness.

Research Objectives/Question

The Research Objective:

The research seeks to achieve many objectives. The most important objective is to minimize the time spent during the Royal Saudi Air Force F-15 Maintenance process. That will achieve another objective, which is increasing the mission capability of the aircraft.

The Research Question:

Could Lean improve the Royal Saudi Air Force F-15 maintenance processes?

Research Focus

This research is focusing on the Royal Saudi Air Force F-15 maintenance process. Because of the time and resources being wasted in the process, the Lean techniques will be used to shorten the time for process and to develop better ways to do the job.

Methodology

The researcher will use questionnaires as way to collect data. Questionnaires will be given to different Royal Saudi Air Force departments for response. The idea of these questionnaires is to determine if Lean could help improve the process. Also to discover the unnecessary steps workers can easily identify and consider a waste. After collecting the data, information will be analyzed and Lean techniques will be used to develop process.

Assumptions/Limitations

This research deals with the available resources and will not try to go deep into any financial matter or administration process. It will focus on the maintenance squadron and has no relationship with any other squadrons outside the Logistic Wing.

Implications

This research will help in improving the F-15 maintenance process in the Royal Saudi Air Force Maintenance Squadron by shortening the process time and by the better use of resources.

Preview

The objective is to shorten the time required to make all the F-15 aircraft fully mission ready for their first flight. Another objective is to eliminate the need for overtime and minimize the daily work hours to 16 hours.

II. Literature Review

Chapter Overview

This chapter presents an overview of the salient material investigated while researching the problem statement of this thesis. Although only the literature considered helpful in analyzing this problem is mentioned here, it will be helpful to understanding the conclusions reached in this work.

How Lean started

The Japanese were the first to change the rules of the game. Taiichi Ohno (production and executive in Toyota Company) purchased a few used American presses and endlessly experimented from the late 1940s onward. He improved the way for die changes to an improved quick one. His idea was to make the die-change techniques simple and to change dies frequently- in shorten time intervals versus two to three months. He used rollers to move dies from and into position and as a simple adjustment mechanism.

By the late 1950s, Taiichi had shortened the time required to change dies from a day to just only three minutes. He also got rid of the need for specialists whose job was to die-change. He made an unexpected discovery in the process. Small batches of stampings actually cost less per part to make than enormous lot run-offs. Manufacturing small batches removed the cost of carrying huge inventories of finished parts that mass-

production systems required. It also helped to discover and correct early problems because it showed stamping mistakes almost instantly.

The result that small batches were more productive than large batches was huge and great. It caused the personnel staff who work in the stamping shop to be more concerned about quality, and it eliminated the waste resulting from large numbers of defective parts. Such errors were expensive to fix and repair, or even to neglect and discard. Such errors were often discovered only long after manufacture was completed. Ohno needed both a highly skilled and an extremely motivated work force to make this system work at all and be successful. If employees failed to solve the problems before they happen and they didn't take action to come up with a solution, the work of the factory could stop easily.

The system of the mass production assumed the workers on the production line would perform not more than two simple tasks, repetitively. The foreman ensured that all line workers followed orders and did not do any assembly tasks. The industrial engineer developed these orders because he was also in charge for improving the process.

Repairing tools, housekeeping and quality inspections were made once discovered and fixed in a rework area after the end of the line by special workers for every task. In addition at the utility man, filled in for those employees who didn't show up each morning.

Headquarters managers in general measure their factory management based on two criteria – yield and quality. The number of cars produced in relation to the scheduled number is yield. Quality was measured after vehicles with problems in the parts had been repaired. Factory managers realize and recognize that the production goal should be

accomplished at all costs. The end of the line mistakes could be fixed in the rework area but before the cars reached the quality checker from headquarters stationed at the shipping dock. Because of that, it was important that the production line continue on working unless important things happen. Allowing cars to go on down the line with parts that are not fit well was acceptable, because this type of defect could be fixed in the rework area, but that type of rework's cost a lot.

Ohno realized this complete system was full with *muda*, (waste). No one of the workers beyond the assembly workers was adding any value to the vehicle. Ohno believed that assembly workers could do most of the specialists' work and do it better because they are in contacted with the current status on the line.

Ohno started to test and try. He started by gathering workers into teams with a team leader. The teams were given a group of assembly steps and asked to work together to come up with the best performance necessary for operations. The entire team works together, even the team leader. He coordinates the team, and in particular, if any worker was absent he would fill in.

Ohno then gave the team the responsibility of housekeeping the team area, repairs their tool if the team able, and checking for quality. When he see the teams were running smoothly he asked them to put time aside regularly for the team to come up with suggested ways to improve the process.

Ohno realized that the mass-production practice of keeping the line running caused errors to multiply at the end. Ohno came up with the idea of putting a chord above worker and asked workers to stop the assembly line directly if they saw a problem that they couldn't fix. After that, the whole team would come together to try to fix the

problem. Production workers were taught to follow every error back to its root cause and then to give a solution for the fix, so that it would never happen again.

When Ohno's production line fist started to work with his ideas, it kept on stopping most of the time. With experience, the work teams began identifying and follow problems to their main cause and the errors drop. Today in Toyota plants, yields approach 100 percent. Where every worker can stop the line, the line practically never stops.

Ohno came up with a new idea, called *Kanban* to coordinate the parts flow within the supply system on a daily basis. Parts were manufactured at each step to supply the following step demand. This idea was hard to apply in practice because it removed all inventories. When a part of the huge production system failed, the complete system would fail too and stop. This was because of Ohno's idea. It focused the huge production process member on solving problems before they became really deep problems that stopped everything.

Toyota with time stopped manufacturing cars that were built in advanced for anonymous buyers and switched to a build-to-order system. Toyota dealers started to become part of the production system. The dealer was step number one in the *Kanban* system, sending orders for presold cars to Toyota plant for delivery to particular customers in a few weeks.

Toyota had come to grips with the principles of Lean production by the early 1960s. [1]

Lean and Lean Techniques

Lean aim is a technique of creating value with a focus on the elimination of waste. It is all about delivering the need of the customers and what they want; paying the shareholders back what they invested the way they expected; and workers job satisfaction with lifetime learning that they deserve. Lean thinking helps by giving ways to identify value, reorder value-creating actions in the best way, doing the actions more effectively than before without interruption when they are requested. Lean delivers and figures out a way to do more with less time, human effort, equipment and less space. It results in giving the customers what they exactly want.

Lean thinking includes five major steps. They are:

Specify Value: From the end customer point of view, Lean starts by identifying the 'value' in terms of specific services and products, with specific capabilities and prices for specific customers.

Identify The Value Stream: A 'value stream' is the linking of all actions and steps in the processes which are important and necessary to change the raw materials into the final finished products that the customer wants and needed. After that, the customer is supported by providing post sale activities.

Actions can be classified into one of the follow three categories after in depth analysis of each individual action is conducted by mapping the value stream for a product:

a) Actions create value. How does the action create value?

- It can transform material, people, or information into something needed.
- It does the transformation correctly from the outset.
- Is done the way the customer wants it, internal or external customer.

b) Actions that create no value but are necessary and unavoidable take into account the firm's currently capabilities and situation. Based on what is on hand or the current technology, policy, or thinking, some actions cannot be eliminated even if no value is created.

c) Actions that create no value and can be eliminated directly. These actions consume resources without creating value in the eyes of the customer.

Actions in both points a and b are analyzed further in an effort to develop the action as far as possible so that the firm can remove unnecessary expenditures of resources.

Make Value Flow Continuously: After eliminating wasteful actions as completely as can be done along the value stream, the firms should try to make the remaining value creating steps 'flow'. The challenge is how to get rid of the batch and queue mentality that is common in mass production and install small lot production mentality instead, with single unit batch sizes as the ultimate goal. The best way to create flow is by eliminating traditional functional organizations, replacing them with integrated product teams organized along the value stream.

Let Customers Pull Value: It is the customer who pulls the product from the enterprise instead of the enterprise pushing the product to the customer. By using and

performing the *Kanpan* system, a production system is organized based on the "just in time" principle. The job of total quality management roots out all defective work.

Pursue Perfection: Firms that have applied Lean principles and exercises find that there is no end to the process of minimizing waste. They keep on developing products and services delivered for the customer. So, in terms of eliminating waste and reducing effort, time, space, and errors, the pursuit of perfection entails a continuous process of improvement. [2]

Principles of Lean Enterprise Value

- Principle 1: By doing the job right and by doing the right job Lean value is created.
- Principle 2: Value should be delivered only after knowing stakeholder value.
- Principle 3: The only way to fully realize Lean value is by adopting an enterprise perspective. The overall net gain will be limited if Lean is not integrated as part of an overall enterprise strategy.
- Principle 4: To increase Lean, the interdependencies value should be addressed across enterprise levels.
- Principle 5: People, not just processes, effectuate Lean value. Lean enterprise value is constrained when workers are not thankful for the knowledge that they have in their roles and experiences.

Muda and the Seven Wastes:

Muda is a word in Japanese which mean waste. Taiichi Ohno, the Toyota executive, identified the first seven types of *muda*:

- Mistakes that require correction.
- Production of products or services that no one wants or needs so that inventories and remaindered goods pile up. These are overproduction ahead of demand.
- Continue performing steps which aren't needed.
- Employee's movement.
- Goods transported from one place to another without any purpose.
- Groups of people standing around waiting downstream because an upstream activity has not been delivered on time.
- Services and goods which don't meet the customer needs.

These categories of seven wastes are actually developed for producing operation but they can be adapted for administrative operations or design operations as well. [3] [2]

Kanban

In 1953 the *Kanban* cards were introduced to formalize the system and to help information flow smoothly backwards and products flow forward at the same rate. A *Kanban* is the attaching of a card to parts in boxes that helps regulate the flow of the production system by signaling upstream production and delivery. It is a visual cuing

system to show that parts, material, and/or information is allowed to move downstream. [3]

The Five S's

There are five Japanese words beginning with the letter S used to make a workplace fit and suited for visual control and Lean production. The five S's indicate personal discipline, habits, and organizational loses that make it easier and helpful to identify the waste.

1. *Seiton* (neatness) = simplify or sort: take out unimportant things from the work places.
2. *Seiri* (organization) = straighten or simplify: arrange tools, paperwork and accessories.
3. *Seiso* (cleaning) = scrub or shine: repair, clean and keep clean.
4. *Seiketsu* (standardization) = standardize or stabilize: start and keep controls and standards.
5. *Shitsuke* (discipline) = sustain or self-discipline: pursue continuous improvement. [2] [4]

Process Walk: Process walks are done by employees. They walk as a team in their work area, trying to identify any wastes that they can see. When they do, they apply "just do it" actions to improve the process immediately. By knowing how to distinguish inefficiencies and resolving problem in their working environment, workers gain skills and habits important to combining Lean thinking into their everyday works.

A3: This tool is developed quickly. It complements organizational strategy by showing the relation between tactical Lean efforts and overall priorities. The idea used in this tool is that the firm teams draw a process or problem that they face in the company using only what they are able to fit on a standard A3-sized piece of paper. This A3 tool provides the team with a means of good inter-team contact. It provides great communication mechanism to describe the process easily and results in a high-level view of the current the steps in the process. After the team improves their problem-solving capacity and gets a fuller understanding of the process, they can use the view of the process on the paper to know areas for develop the process. The A3 tool is used to connect levels of process improvement efforts with the entire overall organizational strategy; to identify areas for fast improvement and to mark areas for potential future development. [4]

What Is The Process

The process is any combination of actions which change inputs into outputs. It may also be defined as a series of individual operations needed to create a design, finished order, or product.

The process outputs go to the customer of the process. There are two main kinds of customers, the internal customer to an organization who pays for products and services, and those external to an organization who receive products and services from others in the same organization. External customers might not be the end user. Customers also drive the inputs to a process through their needs and requirements.

Process Maps: are an organized way to visually see all the related activities and steps which make up the process. The process maps are models, diagrams or schematics that describe how the process is working at the current time or how it should work. Only the understood processes can be developed and the process maps make them easier to understand.

Time and Flow:

A lot of understanding of time is required to make the process flow. These can be improved by eliminating bottle necks and stoppages and controlling the process. Time is a very important metric in Lean process improvements. Time is always used as a metric on a value stream map. The great thing about time is it is measurable and the units are universal. There are several times to measure in processes. They are:

- Wait time: Time Work In Process (WIP) is on pause- in waiting for any reason in buffers or storage. Also call Queue Time or Delay Time.
- Processing time: Time that activities are being performed on work in process. Processing time may divide into Value Added Time (VAT) which is processing time where the work adds value to products and Non Valued Added Time (NAVT), activities associated with processing time where the work doesn't add value to the customer products.
- Cycle time: The time needed to perform and finish all the steps in a process or value stream. It is measured in calendar days as seen from the eyes of the customer. It can be measured for one or multiple tasks or activities, a single process or a group of

processes. Cycle time includes wait time and processing time. Other names: Lead time or span time or throughput time.

- Customer demand or lead time: Lead time starts the moment the customer asks for a product until the product can be delivered to the customer. If cycle time is less than or equal to lead time then pull can be accomplished and if not then buffer inventory is used that can be pulled immediately.

Takt time is the time available to produce something, based on the customer demand. It is not a measure of continuous time, like cycle time, or any of the other descriptions that were mentioned earlier.

Mistake Proofing

Poka Yoke or Mistake proofing is an important Lean concept which addresses integrating quality into the delivery of products. It is a Lean concept to stop errors from occurring in the first place. It stops errors or prevents errors that occurred from moving further downstream in the process or into the delivered product.

Visual Control and Andon

The visual control aid allows knowing the status of the process with quick look. It makes the process visually apparent to everyone involved. It became an important Lean tool if it is used commonly, kept updated, and used for active management of the process.

Andon is a specific visual control device. Typically it is numbers of lights showing what the situation of the process is. Each individual step of the process has a group of lights which show if the step is working as planned, needs monitoring, or needs

quick attention. If action is required in a pull system, the entire process will stop to correct and fix the problem.

5 Whys: One way to a perfect thing is to use the "5 whys." This is done by simply asking why five times in a row. These 5 or less whys usually help to get to the root cause of why the problem occurred. This process determines the root cause of problems so that a corrective solution can be developed and implemented. [5] [6]

Value Stream Map

Value Stream Maps are maps that show all the specific action that occurred along a value stream for a product or service. In eliminating waste, value stream mapping proves to be a useful tool to decrease cost and time to meet customer demands. It can work as a very useful tool in identifying process activity or steps that can be improved to 'do the job right'. The value stream map visualizes interactions and flows between steps and shows linkages between information and product flows. It helps to identify the constraints and wastes in process as well as the process sources.

Lean In Aerospace Manufacturing

In the early 1990s the US Aerospace industries started with Lean when companies and government reacted to post cold war imperatives. The first application of Lean in aerospace was in aerospace manufacturing. The lessons were taken from the initiatives of the automobile and electronics companies' large productions, then moved and applied to aerospace field. The Lockheed Aeronautical Systems Company in the late 1980s founded

a strategic planning team for applying Lean to improve the company performance and eliminate waste.

The team modified the available area to become a redesigned factory by using a new delivery system for components and tooling and a new scheduling system. The team improved store-to-stock production times to 11 days instead of 65 days. It also reduced the work in process to 2 days instead of 35 days. In early 1997, a piece moved through all processes necessary to do the part without interruption. When Lean techniques were applies phenomena resulted production time achieved. It took 3 minutes instead of 12 days and the work in process reduced by more than 95 percent

Lockheed Martin kept on using Lean. A *Kanban* system was used by 2000 to link the in-house fabrication centers for the final assembly areas of the C-130J. Large parts storage areas were eliminated because inventory was reduced significantly.

Rockwell International Aircraft Division was building 777 floor beams in Oklahoma for the Boeing Company. Rockwell in 1993 shipped the pilot set of the 777 floor beam to Boeing. The 777 floor beam was assembled like an erector set. All parts had full-size holes to allow easy assembly and reduce waste in drilling, trimming, or any adjustments to fit. Rockwell 777 floor beam required about 47% less time to assemble than a similar beam for the Boeing 747 aircraft with no hard tools usage or a table to do the assembly.

Between 1993 and 1994 Pratt and Whitney made a reduction in lead times to three weeks instead of eight. The number of pieces in process reduced to 77 from 273 pieces;

the new travel distance of 5800 feet instead of 13670 became possible. Average setup time became 30 minutes instead of 6 hours. Defects reduced to 269 defects per million opportunities. Pratt and Whitney added alert management on the assembly line and at the component centers so that line might stop when a needed part was not supplied.

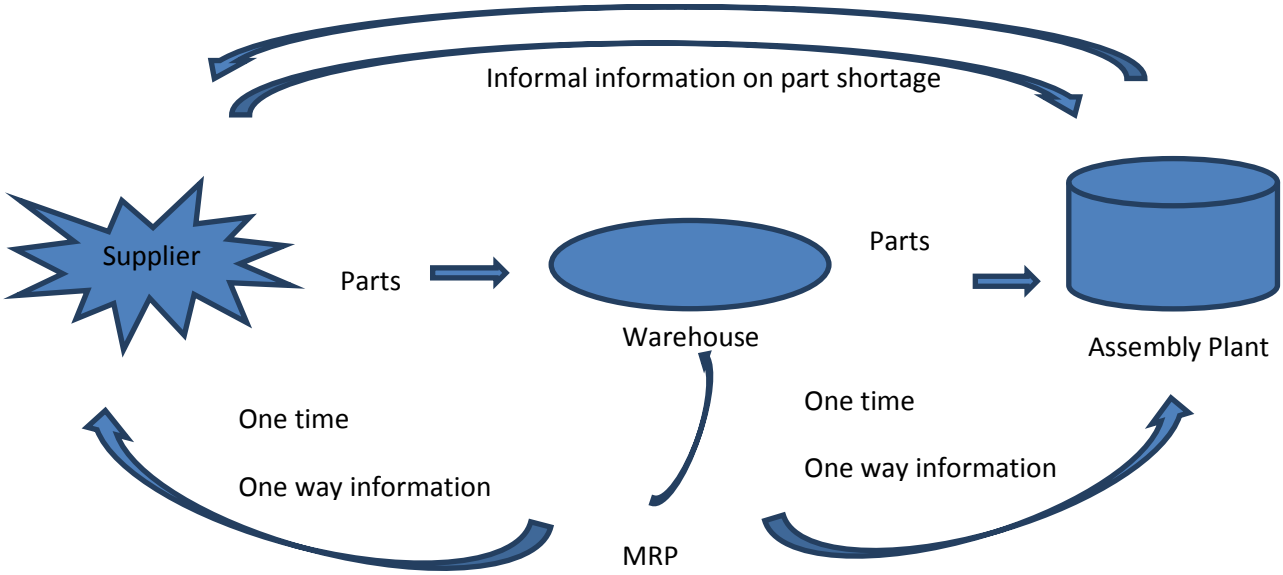


Figure 1. P&W manufacturing system design (early 1997)

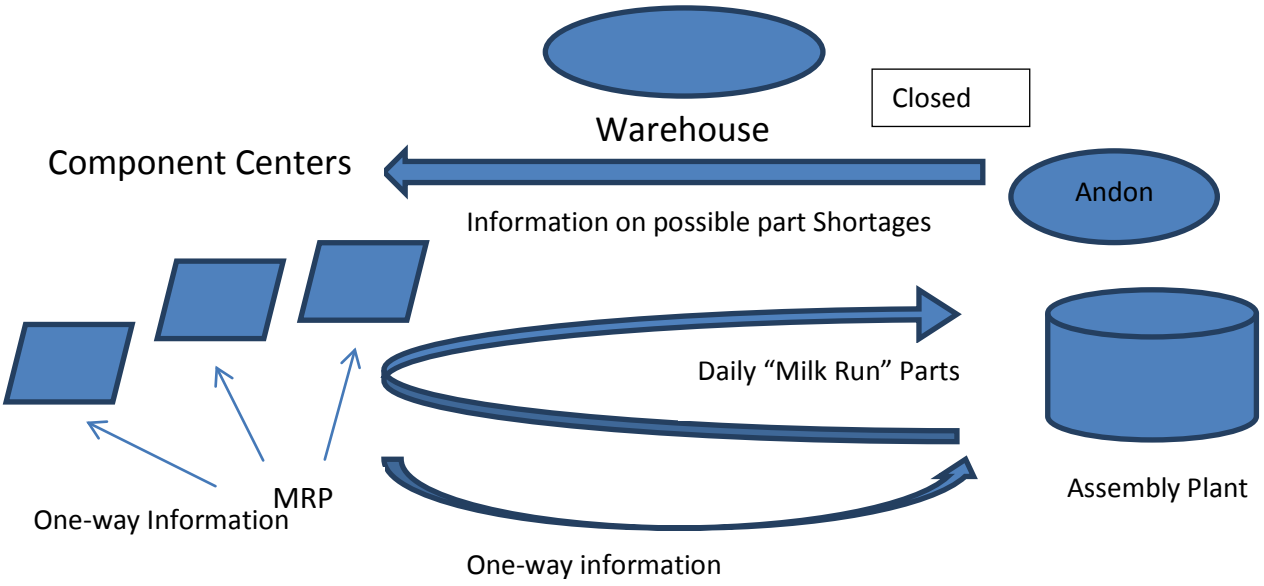


Figure 2. P&W manufacturing system design (late 1998)

In 1997, McDonnell Douglas finished planning its facility design, which required 4 million square feet of floor space, 10 integration and checkout lines, and 20 cranes to transport the huge vehicle parts. In November 1997, McDonnell Douglas introduced the Delta IV people to their 'Lean brothers'. In early 1998, Japanese consultants-former Toyota production executives were brought in by Delta IV. The Japanese visitors overhauled the facility design in about three months. The integration assembly and checkout line saw the most change. In three months it evolved from 10 integration and checkout lines to a single pulse moving line with four cranes instead of 20 and 108900 square feet rather than 4 million square feet. [2]

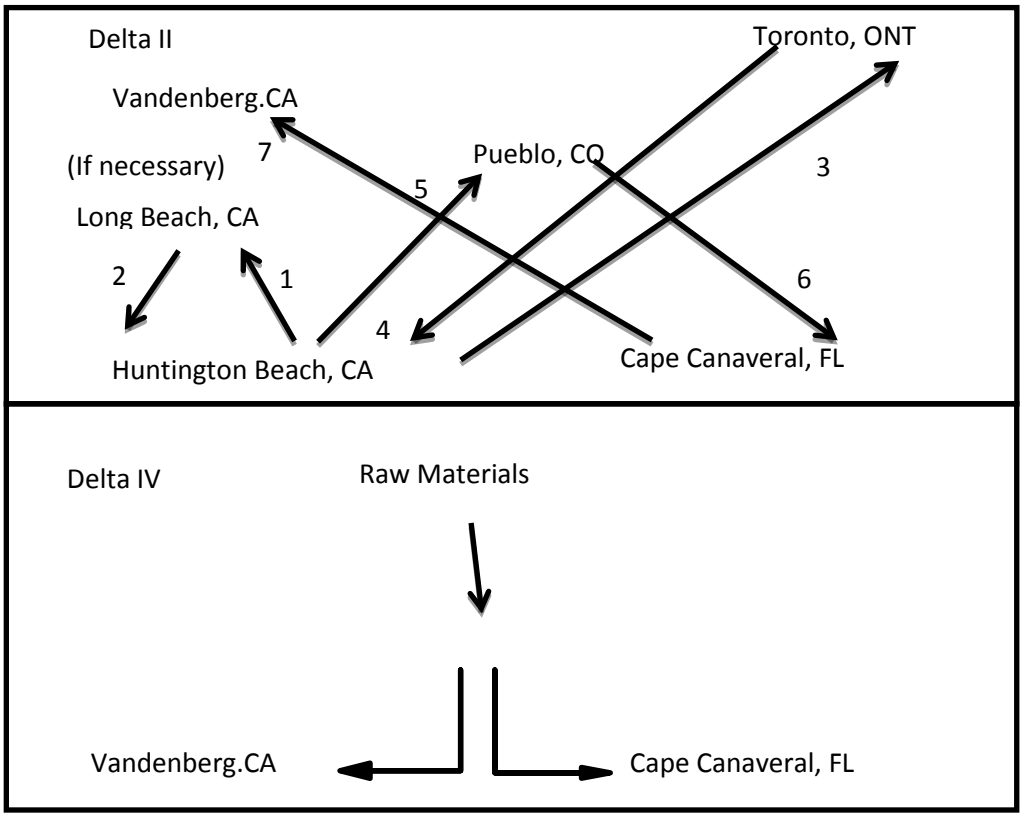


Figure 3. Delta II and Delta IV integration flows

Lean in Air Force

The United State Air Force knows how Lean is important for improving work. Therefore USAF started the Air Force Smart Operations for the 21st Century (AFSO21) which help conducting a successful rapid improvement. The vision for AFSO21 is to start a continuous process improvement (CPI) environment whereby all airmen are actively getting rid of waste and continuously improving processes The AFSO21 is a way to see where the wastes are and eliminate them in any area. It is also an operating principle that simplifies the way material and information flow.

The United State Air Force started using Lean principles for the following reasons:

- The principles required little specialized training.
- They can be applied at all levels and in any type of organization.
- When they have been understood, Lean will spread quality quickly.
- Lean's natural replication is caused by visible results.
- They help other approaches and make them more effective if launched from firms that have Lean processes.
- They build a culture of continuous development.
- The best Lean training is "learn by doing", which means that benefits are realized before training is even complete.

Lean is used now in United State Air Force maintenance at different levels and by using special programs like the United State Air Force Baseline Lean Logistics Master Plan and AFSO21. The Lean Logistics Master Plan provides a cohesive vision of the Lean Logistics concept and guides to apply this program inside the Air Force. One of the Lean Logistics Master Plan methods is "Repair to Demand." The repair to demand concept is employed in Lean logistics to speed the pipeline of repair and fix the problem of the uncertainty of failures. It also speeds time in repair requirements by repairing based on valid requirements as determined by Consolidated Serviceable Inventory (CSI).

The following two figures compare the logistics system before and after using Lean Logistics Master Plan. [7]

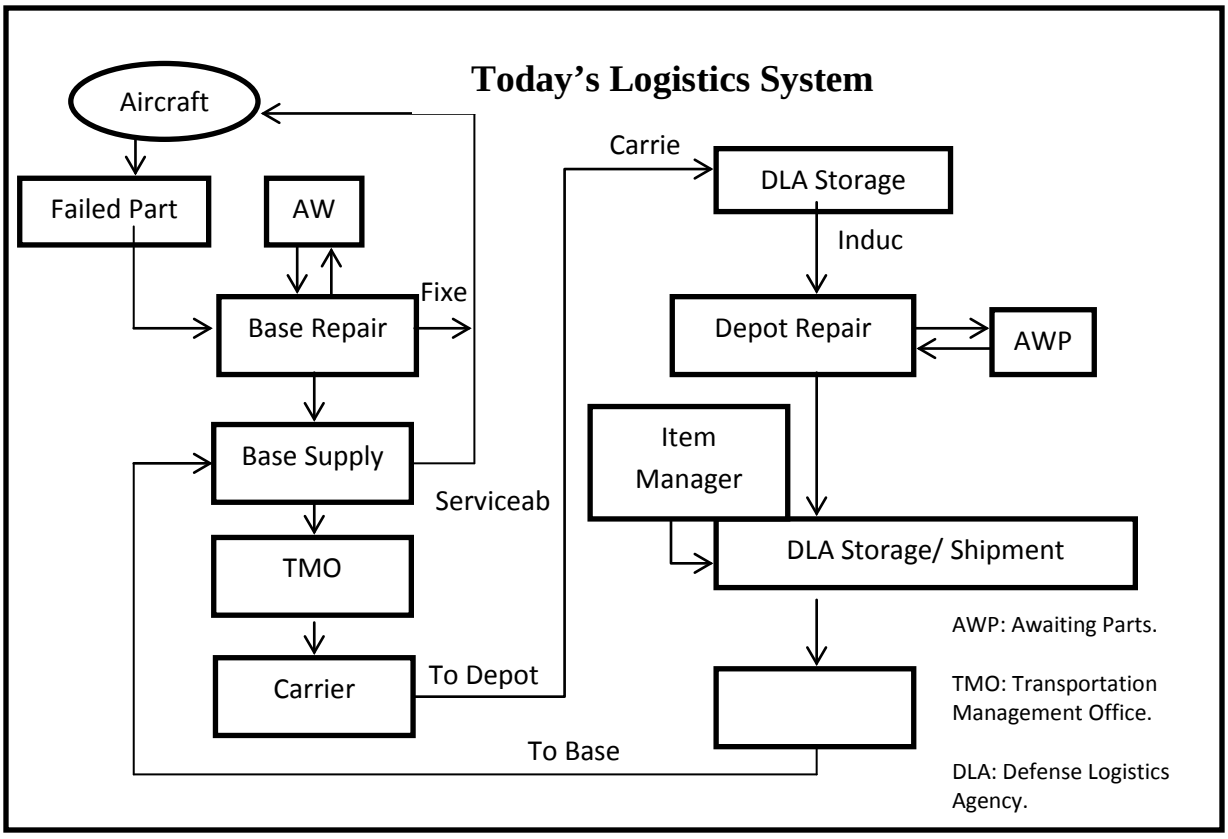


Figure 4. Today's Logistics System

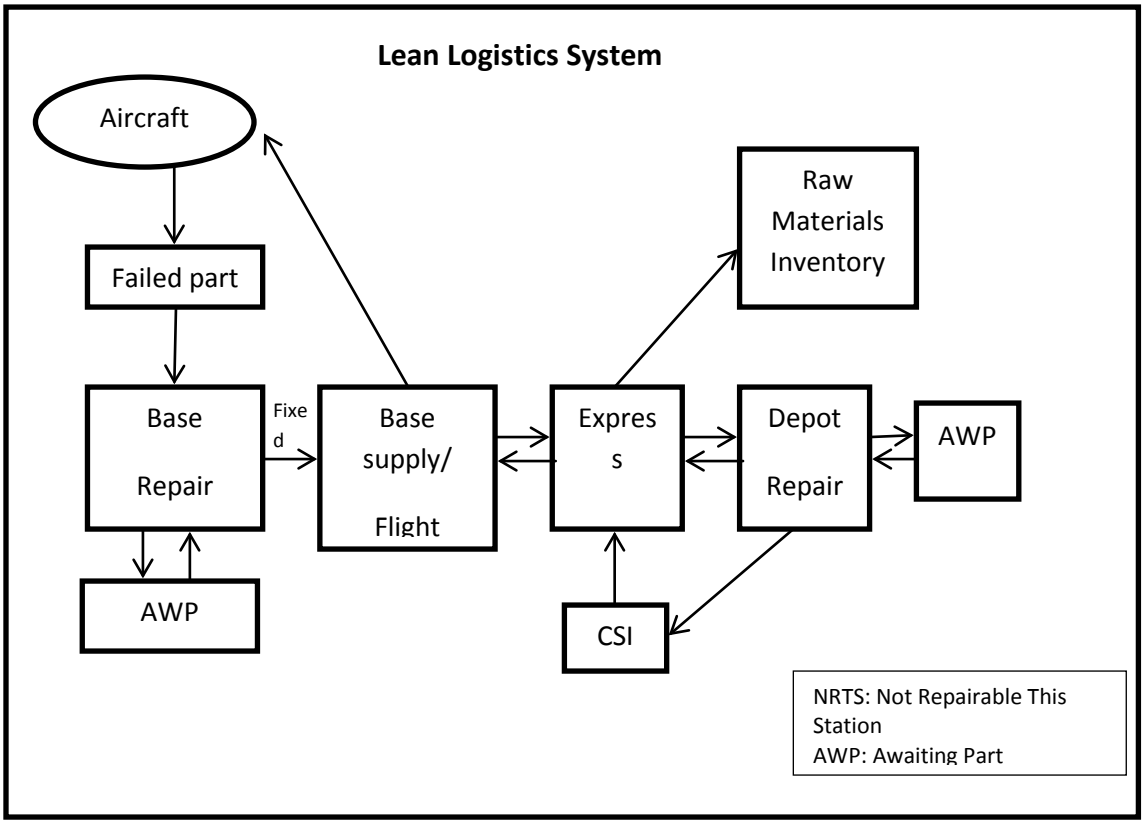


Figure 5. Lean Logistics System

The F-16 Lean Logistics Test Plan is one of the United State Air Force lean applications. It is used to test the application of Lean to the F-16 aircraft, establishes responsibilities, goals, and time lines associated with the Lean Logistic implementation. The objective is to realize cost savings by reducing AF stock levels using centralized stock while keeping the aircraft readiness target. The Lean Logistics Test is performed by using current systems and resources and will show that Lean logistics concepts can be applied.

Robins Air Force Base is one of the United State Air Force bases. It has executed many of different Lean projects that have had environmental results. Consider the following examples.

- C-5 Maintenance Shop: Lean improvements in the C-5 cargo plane shop: "Flow days" reduced from 360 to 220 days. Resource productivity improved by 30-50 percent. $8 million saved in the first year. These developments minimized raw material consumption, use of hazardous chemicals, and waste related with the C-5 maintenance processes.

- C-130 Aircraft Paint Shop: by using 6S techniques (Straighten, Sort, Shine, Standardize, Sustain, and Safety) Robins Air Force Base developed and improved the paint system for C-130 Hercules aircraft. Robins Air Force Base by using many Lean events, increased production, reduced flow days, increased safety awareness in workers, and reduced volatile organic compound emissions, storage space, and chemical use. [9]

One of Lean applications in Air Force is changing selected avionics and engines to two from three maintenance levels, which resulted in:

- Minimizing requirements for intermediate-level maintenance.

- Allowing base-level maintenance reduction, support personnel, facilities and equipment.

- Reducing 4430 manpower positions Air Force-wide from intermediate maintenance.

- Reduces 10 percent equipment purchases and maintenance over the Future Years Defense Program.

By controlling whole aspects of the repair pipeline the Air Force maintains readiness under 2 levels of maintenance. Two levels of maintenance ensure the ability to support contingencies by minimizing the mobility footprint. Two levels of maintenance releases the Air Force from deploying intermediate repair equipment in an F-16 squadron.

[11] [12]

Another important tool of Lean Logistics is what has been called high-velocity infrastructure. This tool provides goods or services in less time to respond a consumer's needs. High-velocity logistics infrastructure emphasizes speed of processing over mass of inventory. It takes 5 to 10 days instead of taken an average 60 to 90 days for Air Force logistics processes to turn a broken reparable component into one ready for use.

Lean In Maintenance

Maintenance generally is a routine and repeated activity. Continual maintenance is needed to keep facilities and equipment in a safe and good condition. This allows it to be utilized at original design capacity and efficiency. In the Lean environment the maintenance organization gains new recognition. The importance of maintenance has

always been high. However, in the past unless there was a problem related production stoppage it was not always given the kind of attention that was deserved. The days of Lean thinking have raised the bar for the maintenance operation and its practitioners. Reacting to the new level of attention should be done professionally, continual learning, observing and recognizing new and better ways of performing. [6] [7]

Success In Lean

There are five key elements for successful process improvement efforts involved in the Lean transformations. Together these five elements help develop a continuous improvement culture. They are:

- Leadership.
- Process improvement methodology.
- Communications.
- Performance measurement.
- Training and capacity building.

Supportive leaders can influence the confidence of others who are important in making improvements a reality. Leadership is so important in allowing great success between individual Lean improvement events and agencies' overall process improvement initiatives.

Employees at all levels can use and adopt the structured problem-solving approach that functional process improvement initiatives rely on. Lean is really based on the Plan-Do-Check-Act continual improvement cycle. The cycle has tools to help employees know the standard process to identify when deviations occur and then make corrections to return back on course.

Internal and external communications are critical and important aspects of effectively conducting Lean events. The effective communications strategy helps make difference between something that hardly works and something that works and grows greater with time. Leadership supportive messages are important because without them Lean efforts face difficulties for success.

In a Lean production system, performance measurements should receive close attention. This attention includes important elements of value to the customer such as time, quality, and cost.

Training and capacity building are important bases for continual process improvement programs. Also training and capacity building are keys to ensure a continual improvement culture within an organization. In the meantime, as with many aspects of Lean, training should apply value-added focus. Many organizations starting with Lean think they need a lot of training before starting the process improvement activities. Lean is mainly a “learn by doing” approach. That is why many Lean training courses do real life exercises to give trainees opportunity to sense how Lean concepts and tools work in practice. [10] [11]

III. Methodology Steps

This research is about developing the F-15 maintenance process in the Royal Saudi Air Force. Because the researcher is a student in the Air Force Institute of Technology in the United State of America, strategies and research plans take into account the distance between the two countries. Some international coordination was required to carry out this research effort. The research plans are described in full detail.

Step1. Start with an initial research plan draft: The research plan discussed with the research advisor Dr. Heminger and research committee Dr. Oyama in regular meeting conversation. The plan was submitted in a draft paper.

Step 2. Complete the CITI training: Because the researcher is from Saudi Arabia, he didn't have a chance to participate in the *Collaborative Institutional Training Initiative* (*CITI*) test prior to this program. The Collaborative Institutional Training Initiative Program's mission is to provide educational content that promotes the quality of and public trust in the research enterprise. Another reason to do the Collaborative Institutional Training Initiative Program is to get the IRB exemption. The researcher's advisor, Dr. Heminger, made inquiries to ensure the researcher has to do the test, since the research is about Royal Saudi Air Force and the individuals who are going to be interviewed are from Saudi Arabia. The researcher took the following tests after Dr. Heminger confirmed that the researcher should take the tests: Air Force Research Laboratory basic course and refresher course, the Basic Course for CITI Health

Information Privacy and Security for Students and Instructor and stage 1 in conflict of interest. The researcher passed these entire tests.

Step 3. Get an IRB Exemption: The researcher had to get the IRB Exemption. For the exemption to be approved the researcher had to write an Exemption Request Letter. The Collaborative Institutional Training Initiative certificates, curriculum vitae for the researcher, copy of the survey questions and a short description of the research were also attached.

Step 4. Contact the Royal Saudi Air Force Attaché and HQ: The researcher contacted the Royal Saudi Air Force Attaché to get information about how to start the research interviews and get the needed permissions. The researcher was told that he should write a letter through his chain of command. The letter should provide a short description of the proposed thesis. The researcher should attach the questionnaires to the letter. The researcher did that and sent the letter and followed the RSAF procedures to get the needed approvals.

Step 5. Discuss the plan with the committee: Dr. Heminger supported some steps, recommended others, and discussed the whole plan with the researcher. Following the meeting with Dr. Heminger and the research committee, Dr. Thal, sample questionnaires were prepared. Dr. Heminger indicated some of the questionnaire's questions should be rewritten to be easier to understand. The research advisor also recommended adding some questions intended to show that Lean could help improve the F-15 maintenance process. Dr. Heminger also emphasized that questionnaires should be retested before sending.

Step 6. Agree on the final general plan idea that would work for the research: After discussions, the research committee agreed on the final methodology and gave the researcher the green light to start. The plan in short started by collecting data through phone interviews and questionnaires. Then, analyzing the data and developing a process flow map for the F-15 maintenance process. This process flow map was being given to a Lean expert who gave his recommendation to improve this process. The researcher will do the recommendation and compare the results with current process to see how much improvement could be achieved.

Step 7. Write the questionnaires: The questionnaires were developed to provide the kind of answers needed to address the F-15 maintenance process. Four questionnaires were developed for different purposes. One of the questionnaires was made for Aircraft Maintenance Administration staff. Two of the questionnaires were for the F-15 Maintenance Aircraft staff. The last one was for the customer of the F-15 Maintenance Squadron which is Operations Squadron.

Questionnaires were written in both English and Arabic. The English because it is the research written language. The Arabic because the questionnaires were given to Saudi Air Force staffs that might have some difficulties in understand the English version of the questionnaires. The questionnaires were written and interviewed in Arabic to make sure that Royal Saudi Air Force individuals wrote and answered without feeling language obstacles that could prevent them from explaining answers in full detailed. The questions were written in different ways. Some were yes no questions and others short answers

questions. Also the Arabic answers were translated into English to be readable and attached in the research for the reader.

Questionnaire no.1

Q1- In the F-15 maintenance process, has there any current or previous attempts to apply Lean?

(If yes, more detail information is required)

Q2- Has there any other kind of management attempts to improve the F-15 maintenance process?

(If yes, more detail information is required)

Q3- Is there any Royal Saudi Air Force Manuals book that show how the F-15 maintenance process should perform?

(If yes, more detail information is required)

Q4- Is there any Royal Saudi Air Force regulation that prevent improving the F-15 maintenance process?

(If yes, more detail information is required)

Q5- Do you think F-15 maintenance process can be improves?

(If yes, more detail information is required)

Q6- Do you think F-15 maintenance process has a lot of wasted time or unnecessary movement?

(If yes, more detail information is required)

Questionnaire no.2

Q1- How many years did you work in maintenance squadron?

Q2- What is your current job discrepancy?

Q3- How many years or months' you worked in your current job?

Q4- How many hours you suppose to work weekly and how much over time you work?

Q5- Can you name the F-15 maintenance process main problem?

Q6- Do you think F-15 maintenance process has a lot of wasted time or unnecessary movement?

Q7- Can you name unnecessary step in the F-15 maintenance process?

Q8-What is the thing that you want to develop in F-15 maintenance process?

Q9-What are the obstacles that you face that prevent you from developing the F-15 maintenance process?

Q10- Describe in steps how the F-15 maintenance process perform?

Q11-Who is your customer and what is he looking for?

Q12-Are you a customer in any step, and what are you looking for?

Questionnaire no.3

Q1-what are the average daily work hours to perform the F-15 maintenance process in the last three months?

Q2-What is the average time for changing main landing gear tire?

Q3-what is the average time for changing the antenna?

Q4-What is the average time for receiving a part from the supply?

Q5-What is the average time for changing the fuel jet started?

Any data or charts the analysis department can provided and will be helpful in the research will be attached.

Questionnaire no.4

Q1-As a customer for the maintenance squadron what do you want from it?

Q2-Would you participate in improving the F-15 maintenance process?

Q3-From your point of view what do you think that the maintenance squadron should focus on in F-15 maintenance process?

Step 8. Discussion of the questionnaires with the committee: Each questionnaire was discussed and reviewed by the committee concerning why they are necessary and their potential benefits.

This research considered improving the F-15 maintenance process which meant the process itself. This made the research's first aim the data collection of data that could help the research in improving the F-15 maintenance process. The researcher wanted to understand and know what is written about the F-15 maintenance process in the Royal Saudi Air Force manuals, books, and technical orders. What are the existing maintenance process regulations and limitations if there are any?

All of this information and regulations related to the maintenance process is available in one of Royal Saudi Air Force Logistics Department Administrations, the Aircraft Maintenance Administration.

Questionnaire no.1 investigated if there has been any attempt to apply Lean in one of the F-15 maintenance process in the past or currently. Questionnaire no.1 looked for how the F-15 maintenance process should be performed on a step by step based on the Royal Saudi Air Force manuals. It also looked for any previous attempts to modify or develop the process to make it easier or safer. In addition, it was aimed at determining if there are any Air Force regulations that limit or prevent any improvements to the maintenance process.

The information the research collected provided the basic information that the researcher needed to start the journey of improving the F-15 maintenance process. The information was enough to see if there were any administration obstacles to the process improvement. Through this information if was possible to know how the F-15 maintenance process should be done theoretically based on the manuals in order to compare it later with what is done practically in the field.

Questionnaire no.2 looked for any information that is related to the Lean process. Things such as wasted steps that can be improve. Also because the workers at the bases who are in direct contact with the F-15 maintenance process could explain the process. Their experience in maintenance provided this research with valuable information. Their answers in questionnaire no.2 were a guide to the researcher as to where and how Lean could be applied.

Questionnaire no.2 was also given to the F-15 maintenance squadron staff at one base in Saudi Arabia. Questionnaire no.2 was also given to five maintenance squadron individuals who were working in the Aircraft Generation Flight and they are:

1- The Aircraft Generation Flight Commander.
2- The Aircraft Generation Flight Superintendent.
3- The Aircraft Generation Flight Cell Chief.
4- The Aircraft Generation Flight Controller.
5- The Aircraft Generation Flight Material individual.

The goal of contacting these people in different management levels and in different sections or departments was to make sure that the researcher was aware of all steps currently being practiced in the field and if to ensure that if any of the staff who been questioned overlooked a step, other Air Force members would mention it.

Questionnaire no.2 was developed to collect data that would help to decide if Lean is appropriate for F-15 maintenance process.

Questionnaire no.3 was developed to determine quantitative information pertinent to the F-15 maintenance process. Average daily work hours and average time in performing aspects of some particular F-15 maintenance processes. This data helped the researcher in drawing some figures to study the current F-15 maintenance situation based on 100% correct information.

Questionnaire no.4 and the Lean are all about the customer desires. The F-15 maintenance process is about making the F-15 aircraft fully mission ready for pilots. Some pilots were interviewed to see what they are looking for as customers of the F-15 maintenance process. Also they were asked if they wanted to help improving the F-15 maintenance process and how they could help. All this information was collected from interviewing the customer using questionnaire no.4.

After clarifications and discussions the committee agreed on the purpose for all questionnaires.

Step 9. Agreement on final questions: Each question in the four questionnaires was reviewed, discussed and agreed upon based on what was needed as explained in step 5. For example, the beginning questions in the questionnaire no2 were general questions to identify job discrepancies and expertise for each individual in the maintenance squadron. These questions tried to discover through their answers if the Lean method could be applied in the F-15 maintenance process or not. Lastly, the questions investigated how the F-15 maintenance process is actually performed. Also an open space was provided for individuals at the end of the questionnaire no.2 to write what their thought about the process.

Step 10. Pretest the questionnaires: The questionnaires were given to two Royal Saudi Air Force officers to pretest them in both languages, Arabic and English. The two Saudi officers didn't have any problems understanding the questionnaires. Other Air Force Institute of Technology academic faculties and student were also given the questionnaires as a pretest. These individuals also had no problems understanding the questions.

Step 11. Send the questionnaires in a formal letter to the Royal Saudi Air Force: The researcher sent letters requesting approval to distribute the questionnaires along with the questionnaires through the Royal Saudi Air Force chain of command to the departments that were mentioned earlier. The Royal Saudi Air Force gave the researcher the approval to distribute the questionnaires and start the interviews with Royal Saudi Air Force staffs.

Step12. Start of the interviews: After sending the letter and receiving approval to proceed the researcher started interviewing Royal Saudi Air Force staff members by phone. Other questionnaires were distributed through the formal letter that the researcher sent earlier to get the approval.

Step13. Collect data and information: All the questionnaires responses either by phone interview or by the written distribution to the Royal Saudi Air Force staffs were collected and arranged. The needed information and data was collected from the available resources that the research produced.

Step14. Analyze data and information to write the conclusions and create the process flow map: The available data and information was analyzed by the researcher with a help from the research committee. A lot of helpful information was taken from the questionnaires and interviews. That helped the researcher in developing the process flow map based on the researcher's level of experience in Lean. Collected data and information served as a guide to draw the process flow map. Other data such as time and distance were added to the F-15 maintenance process flow map.

Step15. Contacted a Lean expert to get his recommendations about how to improve the F-15 maintenance process: A Lean expert was contacted and asked to suggest ways to improve the F-15 maintenance process. The idea of contacting a Lean expert instead of using the researcher's experience in Lean to suggest fixes to the process by was done to avoid bias. The researcher's job experience was in the F-15 maintenance process. The Lean expert was given the process flow map with information about how the process is performed. The Lean expert gave his solution based on the available information.

Step16. The researcher applied lean expert recommendations and measure reduction Lean can made to improve the F-15 maintenance process.

IV. Collected Data

The following information was collected by the researcher from the questionnaires that were sent to the Royal Saudi Air Force. The first questionnaire was answered by 3 individuals out of 120 from the Aircraft Maintenance Administration (F-15 Department). The second questionnaire was given to the Aircraft Generation Flight staff. Five employees out of more than 1200 people who work in Aircraft Generation Flight on three different bases participated in answering the questionnaire. The third questionnaire provided information from the F-15 Analysis Department where around 40 people work. Three F-15 pilots answered the last questionnaire.

Questionnaires were sent to the Royal Saudi Air Force and one of the officers there acted as the point of contact and the research coordinator. The Royal Saudi Air Force reduced the number of individuals that the researcher wanted to participate in responding to the questionnaires. Also the Royal Saudi Air Force rejected some of questions in the questionnaires. The researcher coordinated with the Royal Saudi Air Force and got approved to interview some of the individuals via phone calls.

After collecting the raw responses to the questionnaires, all the data and information was described and summarized in bullet lists and charts to make it easier to understand. This process made it easier to understand what kind of information could help in improving the F-15 maintenance process.

Questionnaire number 1

As descried earlier in chapter 4, questionnaire number 1 was given to Royal Saudi Air Force Aircraft Maintenance Administration. The following information was collected from the questionnaire responses:

- Lean has not been applied to the F-15 Maintenance Process at all in the past.
- The Royal Saudi Air Force is still trying to enhance and enforce Total Qualities Management in the maintenance process.
- People provided different answers about if there are Royal Saudi Air Force books or manuals that show how the F-15 maintenance process should be done. Part of Individuals said it performs in accordance with manuals but they could not specify which one. Others named the general manual which shows jobs description for workers in F-15 Aircraft Generation Flight. There were others who said there are no manuals that show the process. This discrepancy indicates that some respondents were confused or didn't understand what the question was asking or they did not have full knowledge of what is inside the manuals.
- The Royal Saudi Air Force has no restrictions or regulations that prevent or limit the developing of the F-15 Maintenance process.
- Individuals in the Royal Saudi Air Force HQ believe that F-15 maintenance process can be developed. Most of them named Team Work as a solution.

- Individuals in the Royal Saudi Air Force HQ agreed that there is a lot of waste in F-15 Maintenance Process steps. The following reasons cited in their responses:

There is no concentration while performing the job, there is no team work, there is no plan before performing the job, time is not enough to do the job correctly from the first time and some people don't care because there are no disciplinary actions taken.

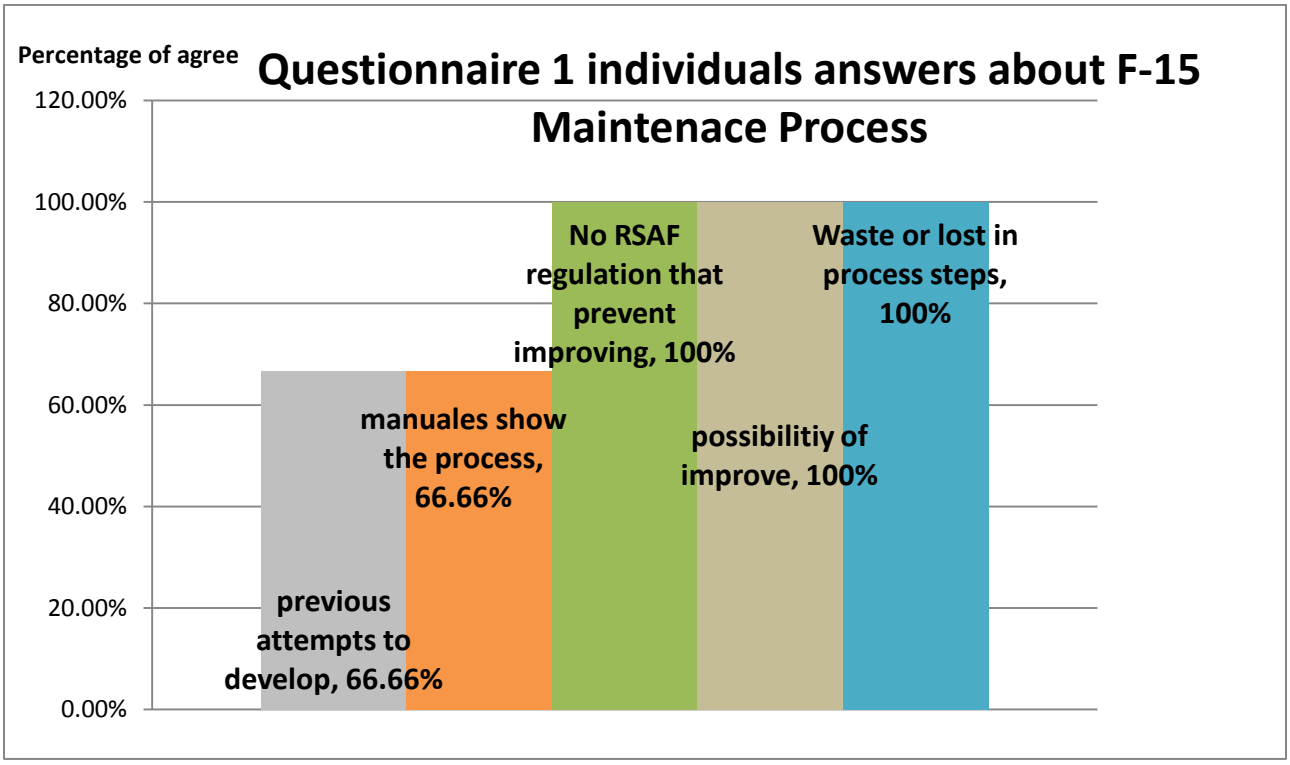


Figure 6. HQ Individuals Responses in Percentage about F-15 maintenance Process.

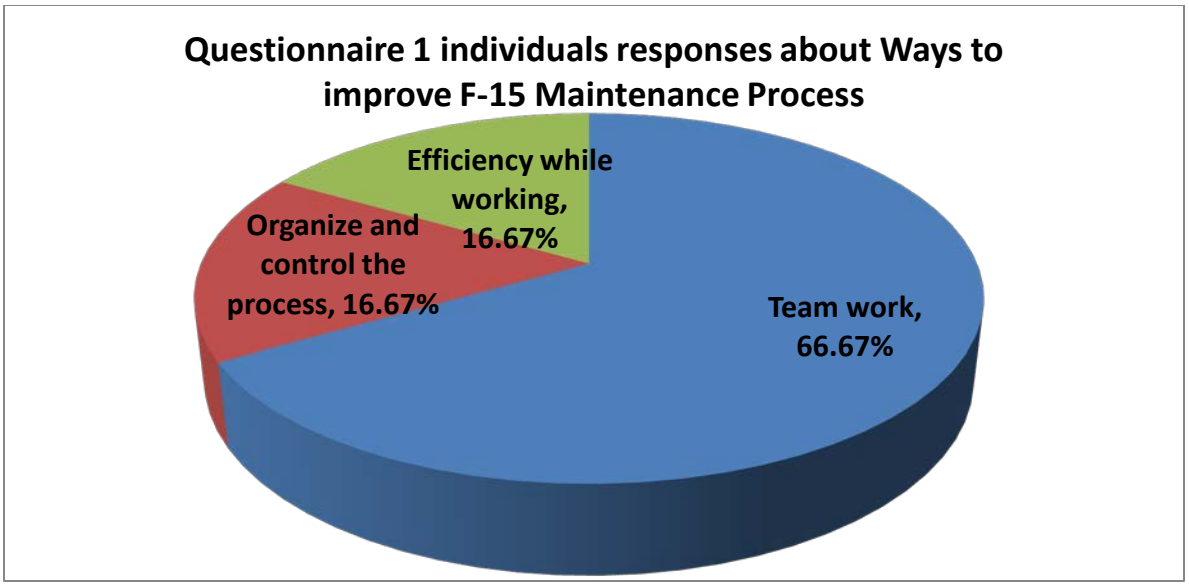


Figure 7. HQ Individuals Responses on How to Improve the F-15 Maintenance Process

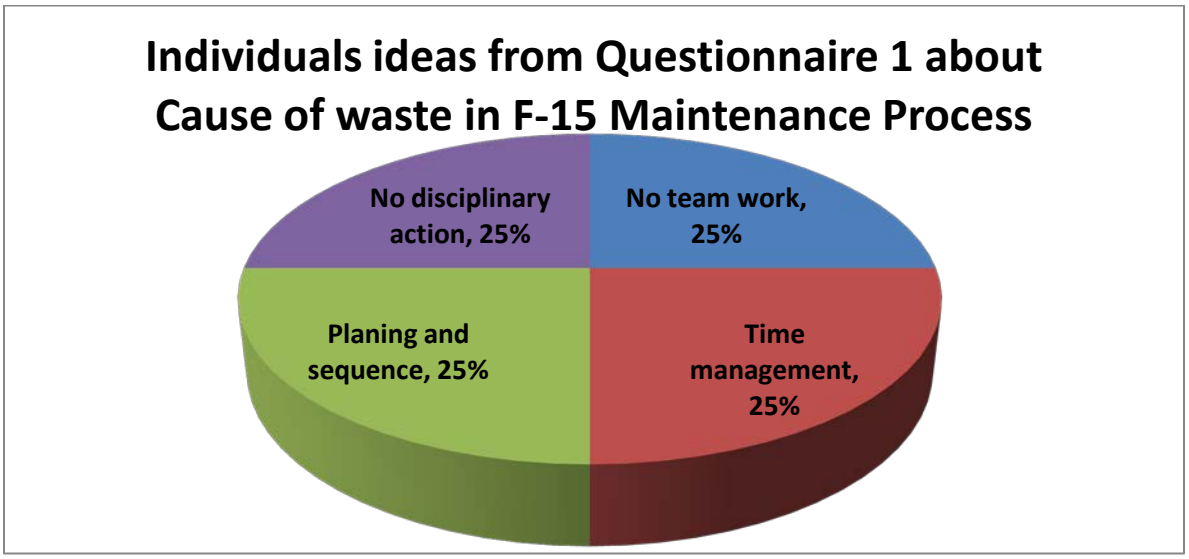


Figure 8. HQ Individuals Thoughts about Cause of Waste in F-15 Maintenance Process

Questionnaire number 2

Researcher gave questionnaire number 2 to F-15 Aircraft Generation Flight individuals. The following information was collected from the second questionnaire responses:

- People who answered questionnaire 2 had 3 to 29 years of experience working in Maintenance. They had different jobs and they were working at different levels.
- The average overtime was 2 hours daily in F-15 Aircraft Generation Flight.
- Some participant couldn't define if F-15 maintenance process needs to improve or not.
- Others named shortage of manpower, supply problems and waiting for support, tools, and parts as solution to improve F-15 maintenance process.
- Most of F-15 Aircraft Generation Flight individuals who answered the survey thought there was no step that could be considered as a waste in the F-15 maintenance process. Some of them preferred to leave the F-15 maintenance process the current way to ensure work quality and safety. Others think there is a waste step but could not identify it.

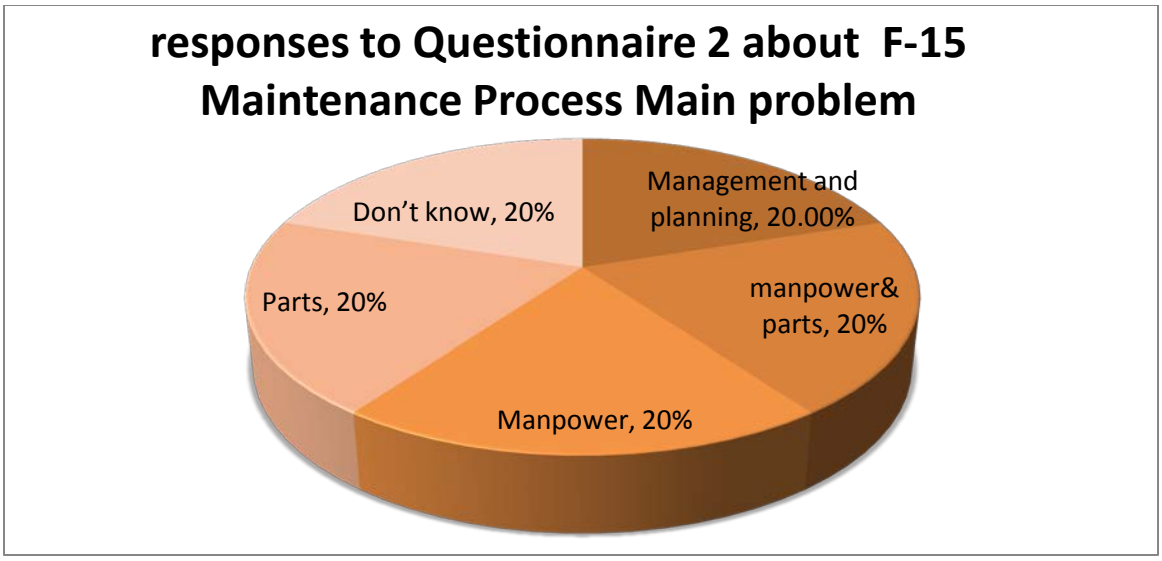


Figure 9. Questionnaire 2 Answers About Causes of delay in F-15 Maintenance Process

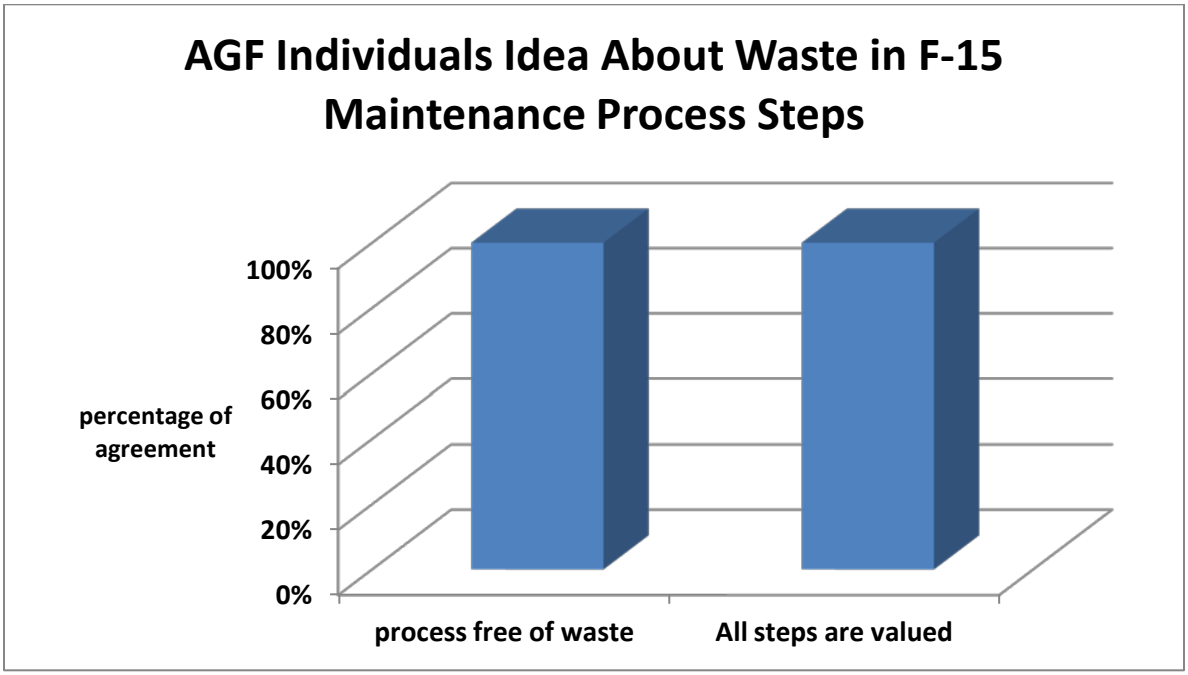


Figure 10. Individuals answers about if there is waste in the process

- When the F-15 Aircraft Generation Flight individuals answered what they wanted to develop in the F-15 maintenance process, their answers were:

  Arrangement, organization, planning, accuracy, focusing, cleaning and all of them agreed on time. These answers contradict their previous responses that there is no waste step in the F-15 Maintenance Process.

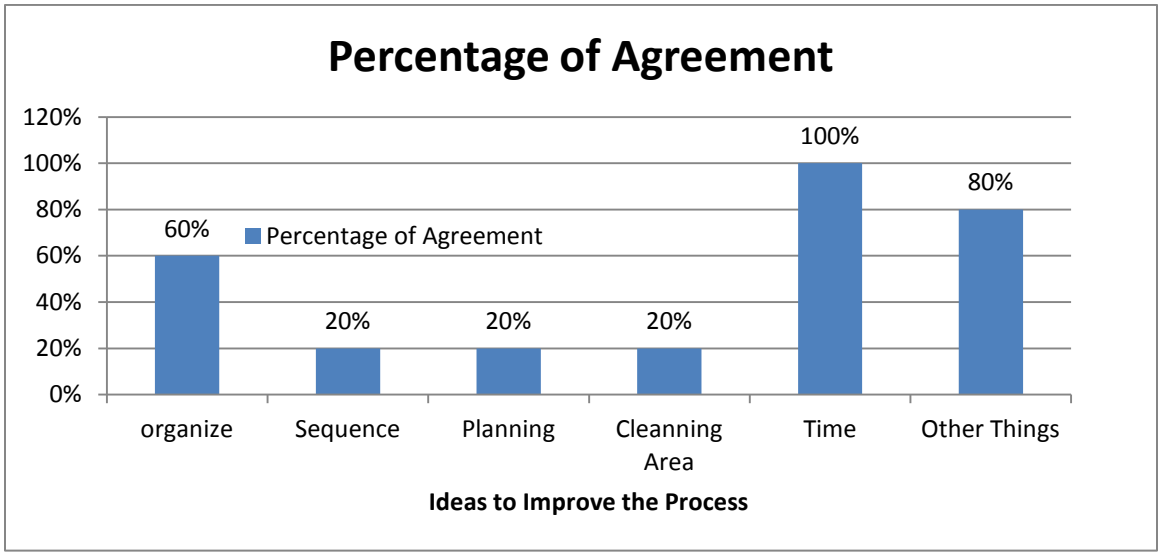


Figure 11. Questionnaire 2 Answers About ways to improve the process

- The F-15 Aircraft Generation Flight individuals thought the rules and regulations of the Royal Saudi Air Force were the main reason that prevented them from developing their jobs relating to the F-15 Maintenance Process.

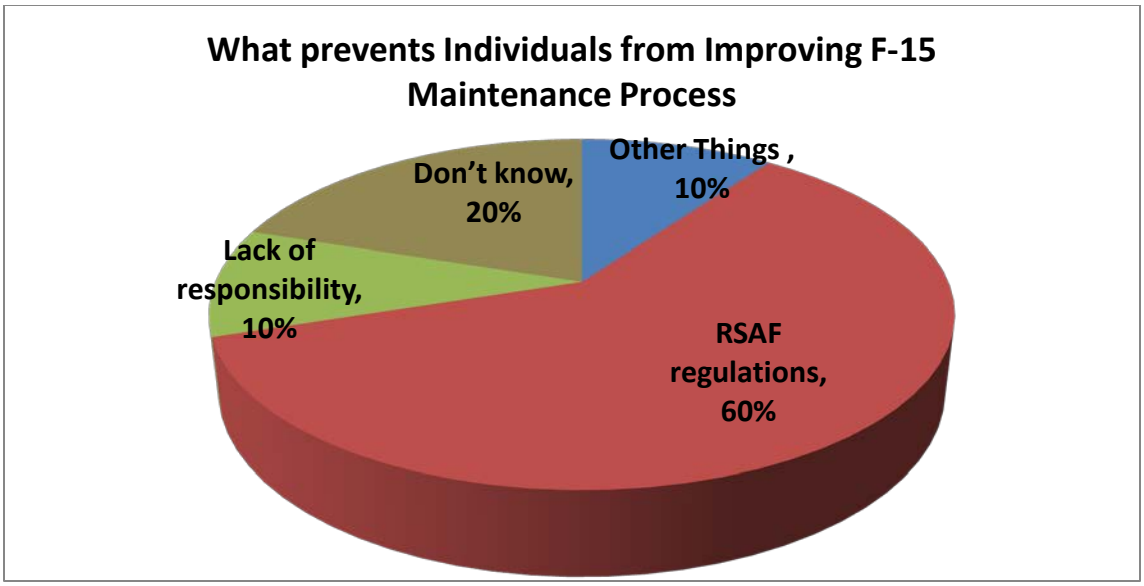


Figure 12. Answers about what prevent AGF individuals from improving the process

- The commanders and supervisors mostly answer correctly about who is your customer. Some subordinate individual's answers were as follow:

  Citizens of Saudi Arabia, the Royal Saudi Air Force, the Aircraft Generation Flight Commander and Maintenance Commander.

This indicates that there is a lack of communication between the management and workers. It implies some of the technicians don't know who is their customer is.

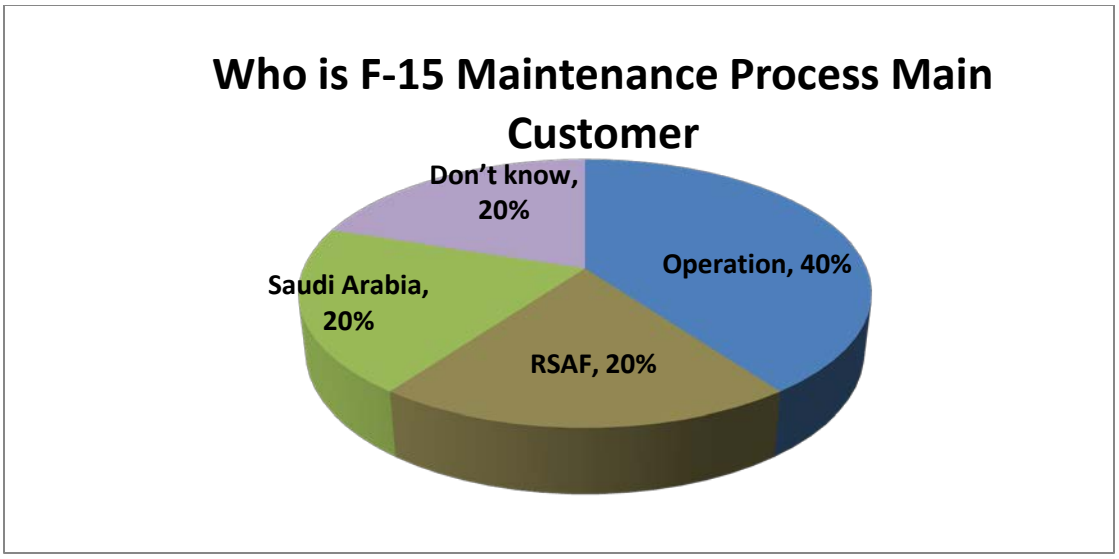


Figure 13. Questionnaire 2 answers for who is the process customer

- No one could answer if he is a customer (need anything from other department in the process) in any step of the F-15 Maintenance Process. Maybe the question was written in ambiguous way.

Questionnaire number 4

Questionnaire number 4 answered by F-15 Operation Squadron pilots. The following information was collected from the questionnaire answers:

The customer for the F-15 maintenance process named the following as what they wanted from the Maintenance Squadron:

Not to accumulate work, Finishing all jobs as soon as possible and Professionalism.

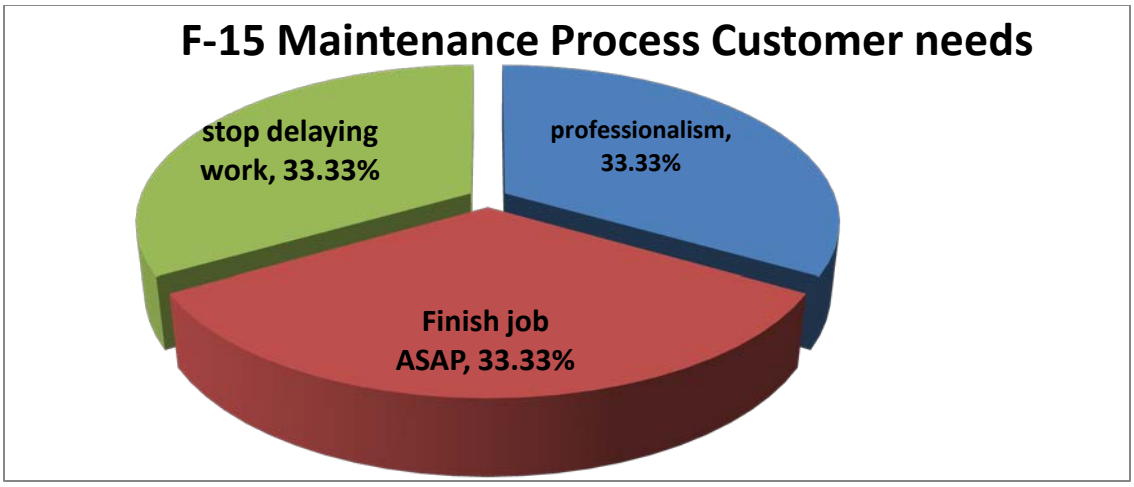


Figure 14. F-15 Maintenance Process Customer needs

- All of F-15 Maintenance process customers who answered the interview said yes, they want to help improving the process and they will help if needed.

- They named many things that they think the F-15 maintenance Squadron should focus on to improve the F-15 Maintenance Process. These included :

  Team work, competition between workers, daily planning for all maintenance work., increase intensification courses for all workers, raise morale, reduce waiting time, increase the coordination between supervisors and their subordinates and reduce the paper work and focus on manpower.

Figure 15. F-15 Pilots Suggestions to Improve the Process

Questionnaire number 3

F-15 Analysis Department answered questionnaire number 3. After reviewing the responses, the researcher thought the received answers were not useful to the thesis and not accurate. The following information should be notice:

- The time to change parts is not constant. Easy jobs that usually require 30 minutes to accomplish might take 4 hours or more in other cases.

- The average work hours for one month shows a lot of overtime work compared to daily work hours. Weekends were excluded from the diagram.

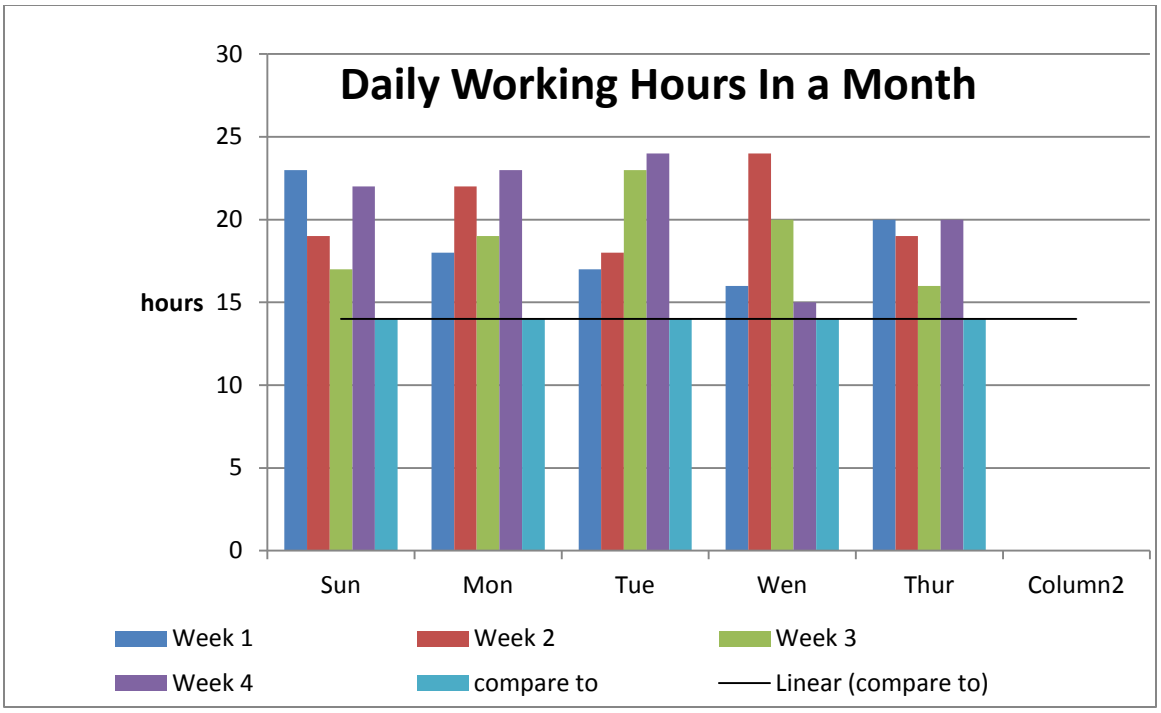


Figure 16. Daily Working Hours in One Month

Process Flow

As part of questionnaire number 2, the researcher asked the participating individuals to describe the F-15 maintenance process and to draw it. The following diagram is for the F-15 maintenance process in the Royal Saudi Air Force

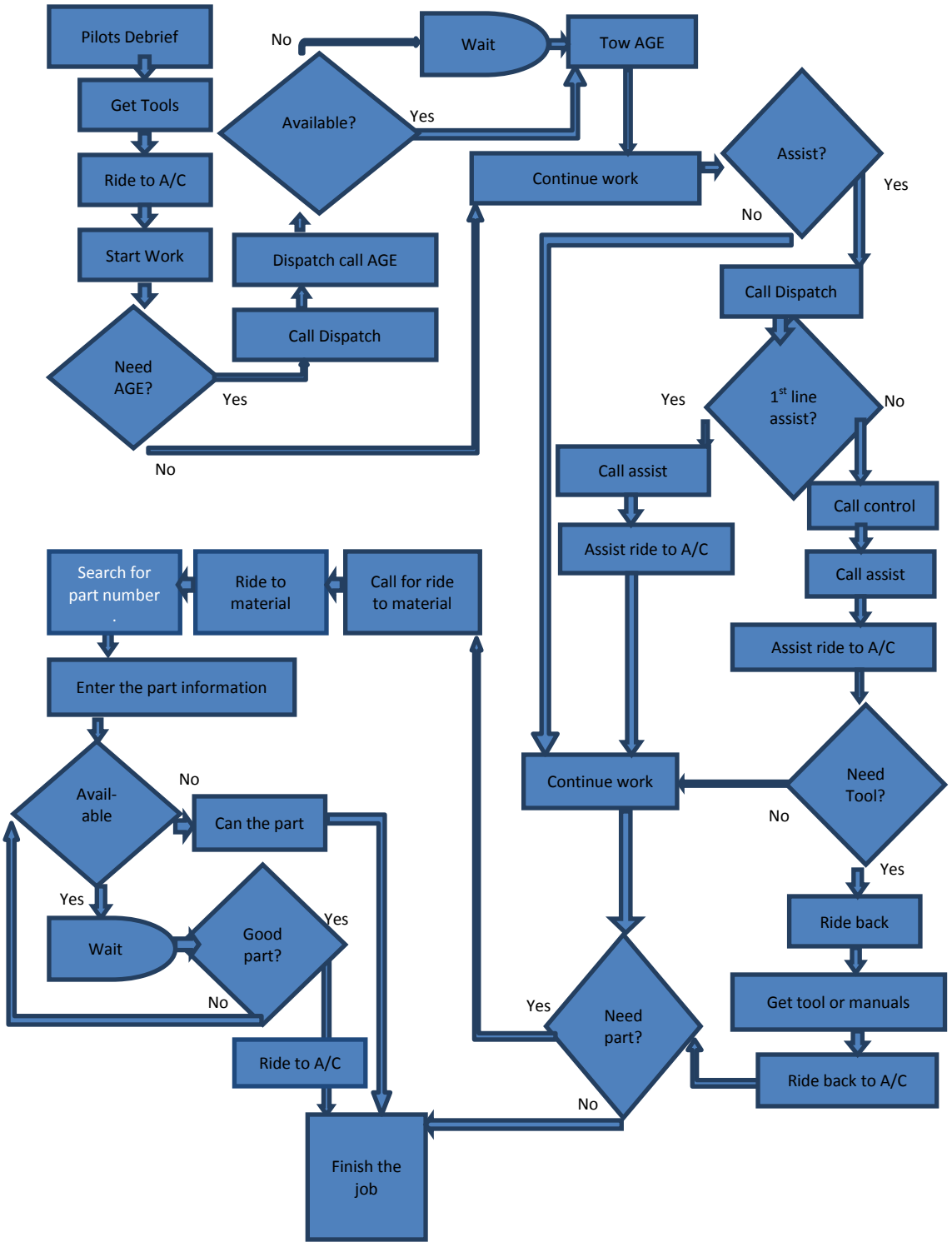


Figure 17. F-15 Maintenance Process Flow

The following steps are the description of the F-15 maintenance process steps in there standard case:

1- Pilot and Technicians go to debrief room. 10-20 minutes.

2- Technicians go to get the needed tools. 3 minutes for each technician.
(After debriefing, technicians go to the support to get tools. They wait in a line to get tools, then inspect the tools, after that, signed that tool is ok, then walk to the bus to get ride to the aircraft). So when we have 6 technicians the last one will get his tool after about 15-20 minutes.

3- Technicians take ride to aircraft. 3 minutes for each technician.
(The bus driver waits outside the support for technicians to get their tools. He waits until the last technician gets his tool and takes them via bus to their respective aircraft. Because each aircraft is in a different location, it takes 10 minutes for the last technician to arrive at his aircraft.).

4- If aircraft needs Aviation Ground Equipment (AGE), technician calls dispatch to ask for the AGE.

5- Dispatch calls AGE.

6- AGE tows the equipment if available to the aircraft.(10-15 minutes to arrive)
If not, the technician must wait until next equipment available.

7- The technician continues with the work.

8- If technician needs assistance, he calls dispatch.(2 minutes to leave the aircraft and call by phone or radio)

a- If the assistance is from the first line technicians, dispatch will call for assistance. (2 minutes)

b- The first line technician assistant rides to the aircraft.(10 minutes including the waiting time for a ride)

9- If the assistance is from some other department, dispatch calls control. (2 minutes)

a- Control calls the other department for assistance. (2 minutes)

b- Other department technician rides to the aircraft to inspect the problem. (15 minutes)

c- The assistant returns back to bring their tools they need. (15 minutes)

d- The assistant gets their tools or manuals. (5 minutes)

e- The assistant returns to the aircraft to begin working. (15 minutes)

a. If the Aircraft needs a part the technicians call for a ride to the material office. (2 minutes)

10- The technicians ride to the material office. (10 minutes)

11- The material office personnel search for the part number.(5 minutes)

12- The material office personnel call supply to order the part. (5 minutes)

13- The supply personnel enter the part information. (5 minutes)

a. If the part is available: technicians wait until the part arrives. (30 minutes-1 hour average)

b. If the part is not available from supply, the part is taken from another aircraft.

c. Check the part if correct or has damage. (2 minutes) If the part is not good, ask for another part.

14- The technicians return to the aircraft with the part. (5 minutes)

15- Complete the work.

16- Finish the job.

As discussed earlier in the methodology the researcher showed the process flow to a Lean expert and got his recommendation to avoid bias. The Lean expert asked the researcher to identify the four or five main possible wastes. To do that, the researcher started to identify the process flow by dividing the steps into value, necessary non-value and waste steps. The researcher colored the process flow to make it easier to identify where these four or five main wastes fell. After coloring the process flow, four main problems were easily identified. The four areas are clearly circled in Figure 18.

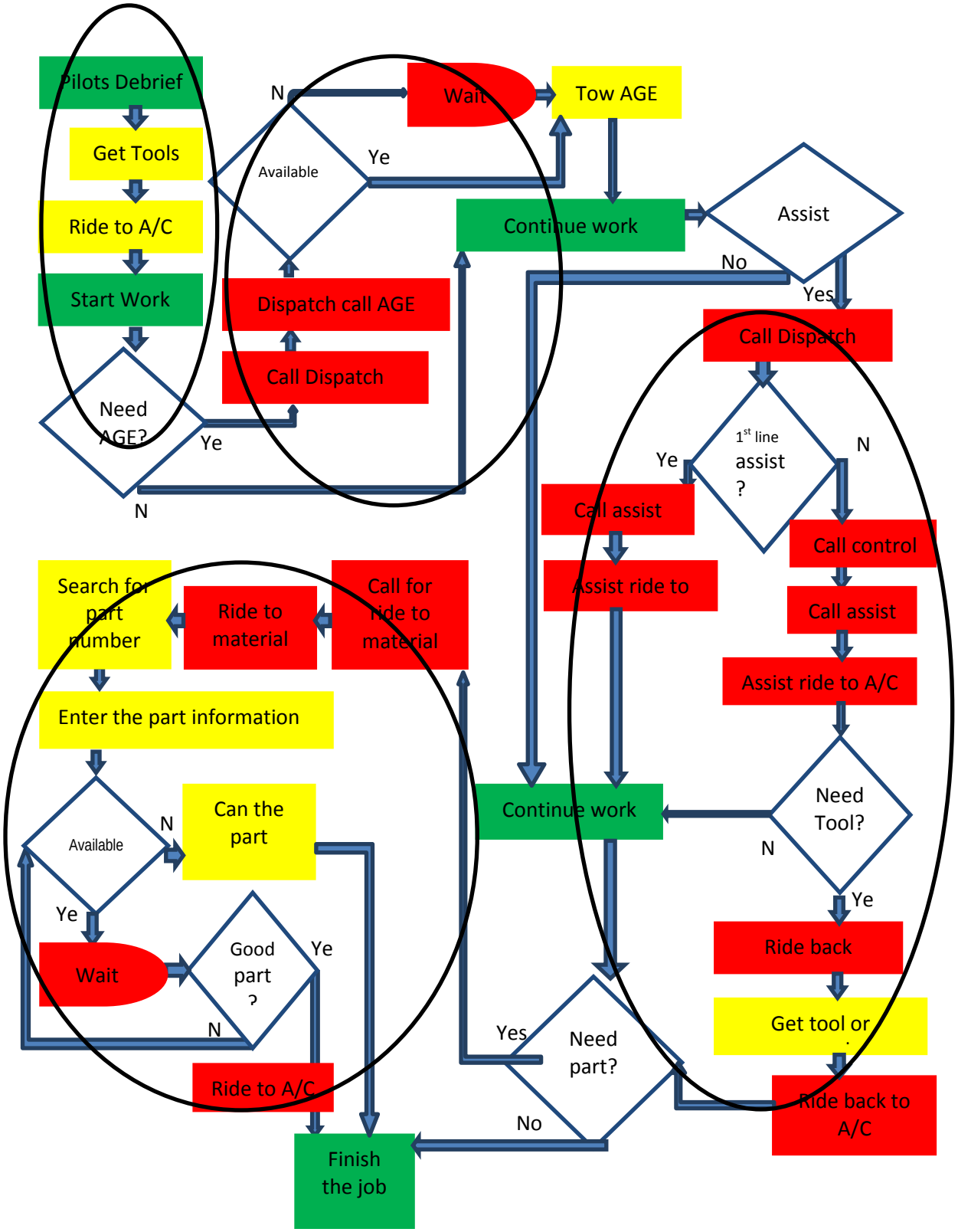


Figure 18. Identifying Lost in F-15 Maintenance Process

From figure.18 it is easy to identify the four main wastes in F-15 maintenance process which are:

1- Pre-work preparation.

2- Asking for Aviation Ground Equipment.

3- Assistance from first line OR some other maintenance department.

4- Ordering parts from supply.

With the Lean expert's help the researcher divide the process flow wastes into three categories.

- Communication.
- Waiting.
- Distance.

As shown in the process flow, the unnecessary steps and waste steps are caused by one of these three categories. It is easy to see that there is a lot of time spent in communication asking for Aviation Ground Equipment, assistance from other maintenance departments or technicians, and contacting supply. There is also a lot of waiting time when technician waits for parts, assistance, and equipment. In addition, there is the distance between Aviation Ground Equipment, supply, other maintenance departments, and the Aircraft Generation Flight.

The Lean expert asked the researcher to consider these because communication, waiting and distance can be measured either by time or by length. Such metrics are used by the Lean techniques to measure the waste and try to minimize it. Based on the Lean

expert's recommendation the researcher did another process flow without the process details. The new process flow just showed the waste in numbers. The Lean expert recommended showing only the worst case. The researcher added the standard case based on the research advisor's recommendation to measure the reduction that we can make in both cases.

The researcher gave samples for communication, waiting and distance in the process flow as A, B and C. Then collected some information about how far location separations were and how long communication and waiting time took in both the standard and the worst cases.

Worst Case and Standard Case

The researcher based on the lean expert recommendation gave a sample for the communication, waiting and distance as mentioned earlier to make it easy to draw and calculate. A sample in figures and tables will indicate time for communication. B sample will indicate time spends in waiting and C will indicate the distance in kilometer.

The numbers 1, 2, 3 and 4 indicate starting of the work and the letters the four main problems the F-15 Maintenance process has. In the following figures and tables show the worst case and standard case.

Table 1 shows time that been spend in communication and the reduction that could be achieved if lean applied. In the following lines a description for each sample and what it is meaning.

A1: The pilot could not find the technicians so he wrote down the information in the debrief computer. A copy of what he wrote went to the dispatch. The time required could be 50 minutes in the worst case before the technicians get the information.

A2: The Aviation Ground Equipment communication takes 80 minutes; 20 minutes to communicate the dispatch and 60 minutes to contact Aviation Ground Equipment (change shift).

A3: a- Assistance from the first line: 20 minutes to call dispatch and 60 minutes to contact the technician (change shift).b- Assistance from other maintenance department: 20 minutes to call dispatch +20 minutes to call control and 60 minutes to call other departments.

A4: supply communication: 20 minutes to reach dispatch or material and 60 minutes to call supply.

Table 1 shows times spend in communication in standard and worst cases comparing to propose that this thesis want to achieve.

Table 1. Time Spend in Communication in F-15 Maintenance Process

Communication (Time)				
	Current		proposed	Reduction in worst
	Standard	worst		
A1	10 Min	50 Min	10 min	(50-10)/50
A2	4 Min	80 Min	1 min	(80-1)/80
A-3a	4 Min	80 Min	1 min	(80-1)/80
A-3b	6 Min	100 min	1 min	(100-1)/100
A4	20 min	80 Min	5 min	(80-5)/80
Total	44	390 Min	18 Min	(390-18)/390

The following is a description for waiting samples:

B1: Waiting to start work in worst case takes 60 minutes.

B2: Waiting for AGE could take 2 hours (change shift).

B3: a- Waiting for 1st line assistance could take 60 minutes (change shift).

b- Waiting for other maintenance departments assistance could take 3 hours.

B4: Waiting for supply could take 4 hours.

Table 2 shows times waiting time spend in F-15 maintenance process in standard and worst cases comparing to proposed that this thesis want to achieve.

Table 2. Time Spend in Waiting in F-15 Maintenance Process

waiting (Time)				
	Current		proposed	Reduction in waste
	Standard	Worst		
B1	30 Min	60 Min	10 min	(60-10)/60
B2	10 Min	120 Min	5 min	(120-5)/120
B-3a	10 Min	60 Min	10 min	(60-10)/60
B-3b	25 Min	180 Min	10 min	(180-10)/180
B4	40 Min	240 Min	15 min	(240-15)/240
Total	115	660 Min	50 Min	(660-50)/660

The following are a description for samples that the researcher used for distance in the F-15 maintenance process. Table 3 shows the reduction that can be done comparing to current case for distance.

C1: Distance in first case can-not be change and it can be neglected.

C2: Distance between the Aviation Ground Equipment area and aircraft area is 1.6 km.

C3: Distance between other maintenance departments and 1st line aircraft is 8 km.

C4: Distance between supply and 1st line aircraft is 10 km.

Table 3. Distance for Movement in F-15 Maintenance Process

distance (km)			
	Current case	Proposed	Reduction
C1	-		
C2	1.6 km	200 m	(1.6-0.2)/1.6
C3	8 km	200 m	(8-0.2)/8
C4	10 km	1 km	(10-1)/10
Total	19.6	1.4	(19.6-1.4)/19.6

Following figures show F-15 maintenance process flow with numerical information about communication, waiting and distance in both cases worst and standard. Followed by some information tables about the cycle time spent in each cases for maintenance job that take one hour.

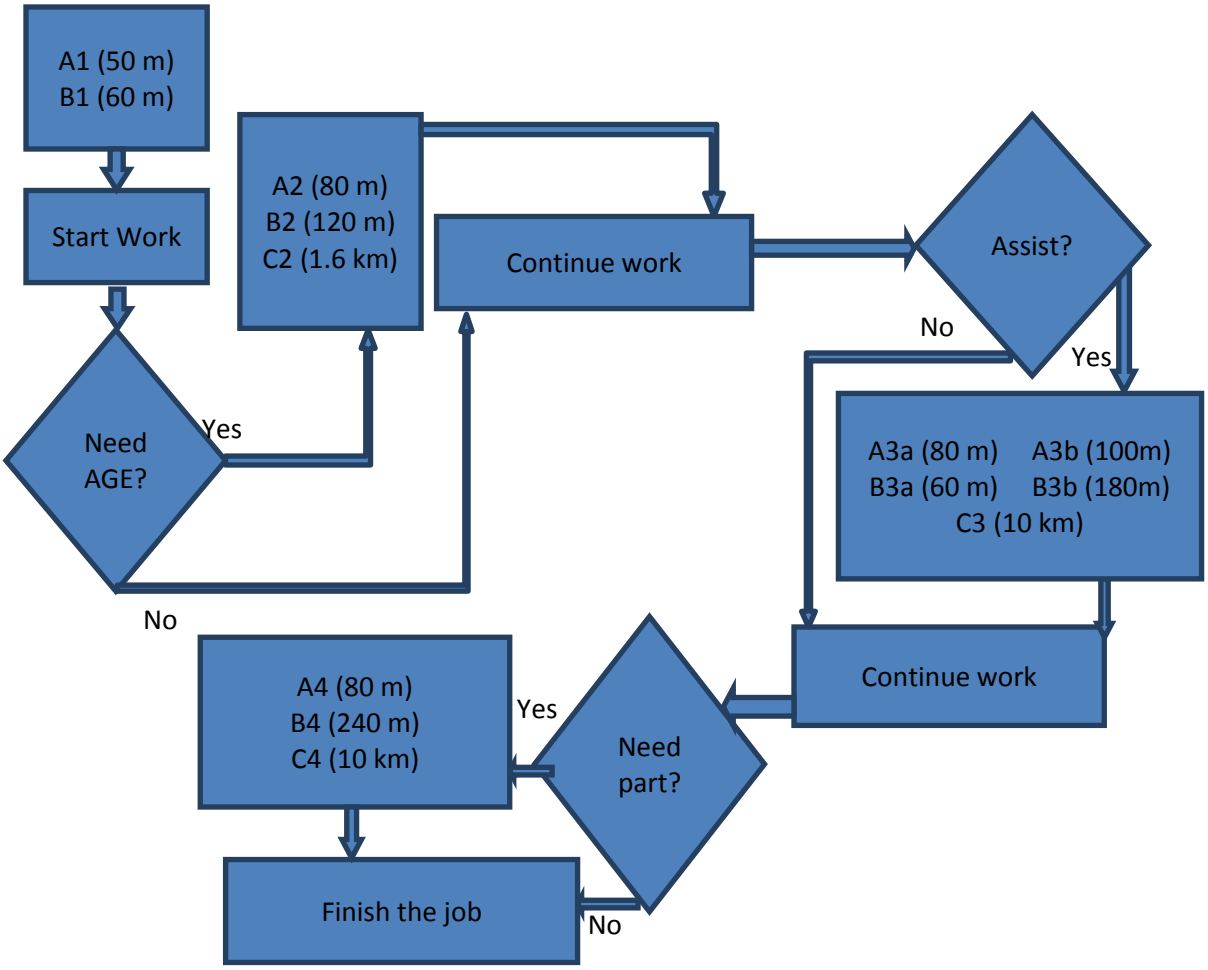


Figure 19. F-15 Maintenance Process Flow For Worst Case

Table 4. Cycle Time For Worst Case

Cycle Time for Worst Case		
PREWORK TIME (PW)= A1+B1=50+60= 110 m		
Need AGE	A2+B2+work time	80+120+work time=200 m +60 m
Need 1st Line Assist	A3a+B3a+work time	80+60+ WT =140 m+60 m
Need Other Assist	A3b+B3b+work time	100+180+ WT = 280 m +60 m
Need Part	A4+B4+ work time	80+240+ WT = 320m+60 m
Total cycle when all needed		PW+200+140+280+320+ 60= 1110m

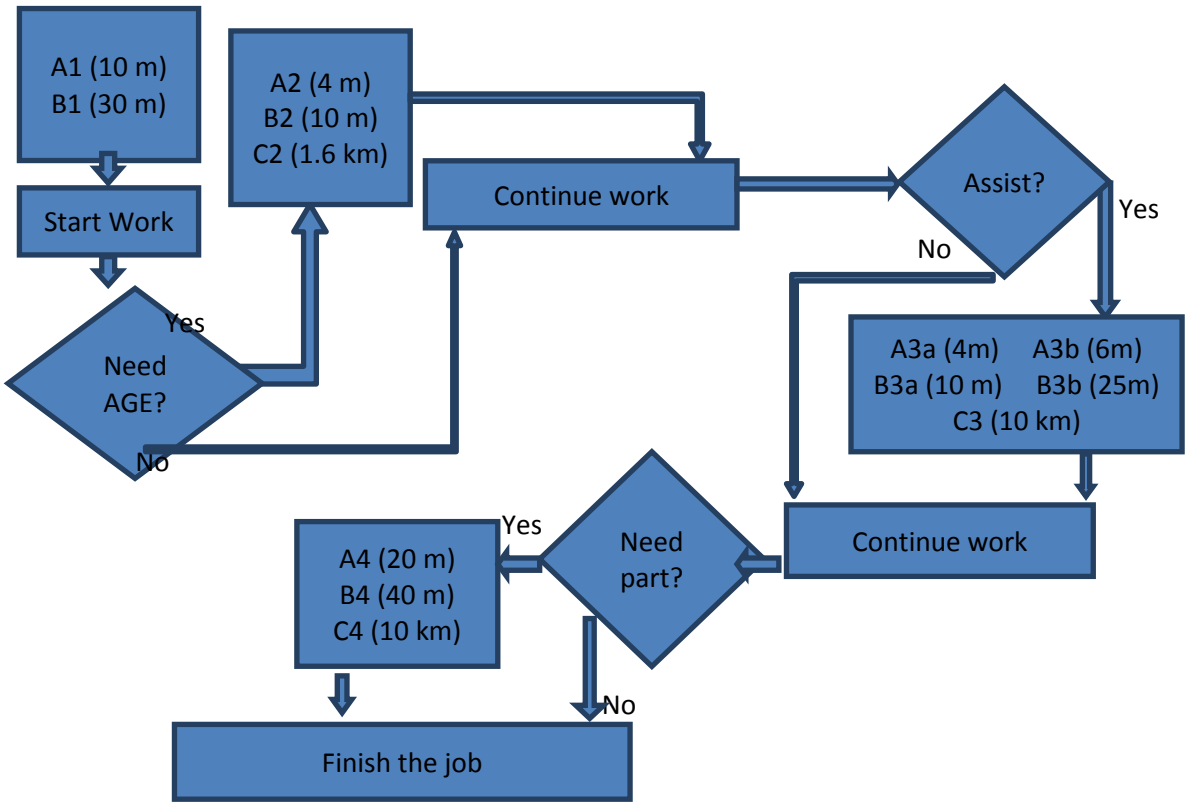


Figure 20. F-15 Maintenance Process Flow For Standard Case

Table 5. Cycle Time for Standard Case

Cycle Time for standard Case		
PREWORK TIME (PW) A1+B1=10+30 =40m		
Need AGE	A2+B2+work time	4+10+work time=14 m + 60 m
Need 1st Line Assist	A3a+B3a+work time	4+10+ WT =14 m+60 m
Need Other Assist	A3b+B3b+work time	6+25+ WT = 31 m +60 m
Need Part	A4+B4+ work time	20+40+ WT = 60m+60 m
Total cycle when all needed		PW+14+14+31+60+ WT= 219m

Improving the process

To improve the process and make the reduction in F-15 maintenance process we recommend the Royal Saudi Air Force to eliminate time that been waste in waiting and extra communication. Another major thing Royal Saudi Air Force should consider is to shorten the distance between maintenance shops, supply and Aviation Ground Equipment. Figure 21 shows distance between supply, other maintenance departments, Aviation Ground Equipment and Aircraft Generation Flight.

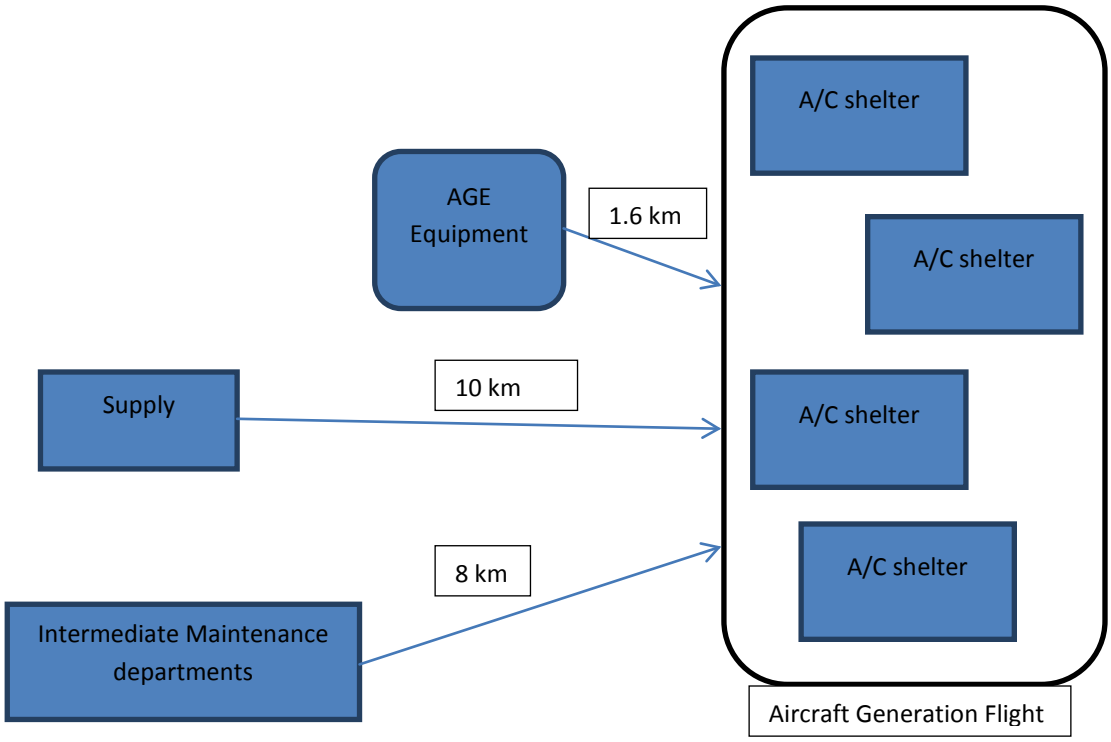


Figure 21. Diagram Shows the distance Between Related Department in F-15 Maintenance Process

The process can be improved by reducing distance. For Aviation Ground Equipment, the distance should be 200 meter in maximum. There is no need to be that far if their main purpose is to help the aircraft get fix. Reducing the distance will surely help reducing the time wasted in movement. The supply also should have closer place than there warehouse. In case of intermediate maintenance departments assist, having their technicians working in the Aircraft Generation Flight area will eliminate the distance completely.

Communication also is another deep issue in the F-15 maintenance process. It can be fixed by using many solutions. One is to have a local network system inside the aircraft shelters that any technicians could access to and ask for what he want either ride, supply part or assistance and get the respond directly with estimating time.

Fixing distance and communication will help reducing waiting time or eliminate it. In case of wait for Aviation Ground Equipment because all of equipment are busy, can be fixed by increasing equipment number. Figures 22 and 23 show the new and improved F-15 Maintenance Process.

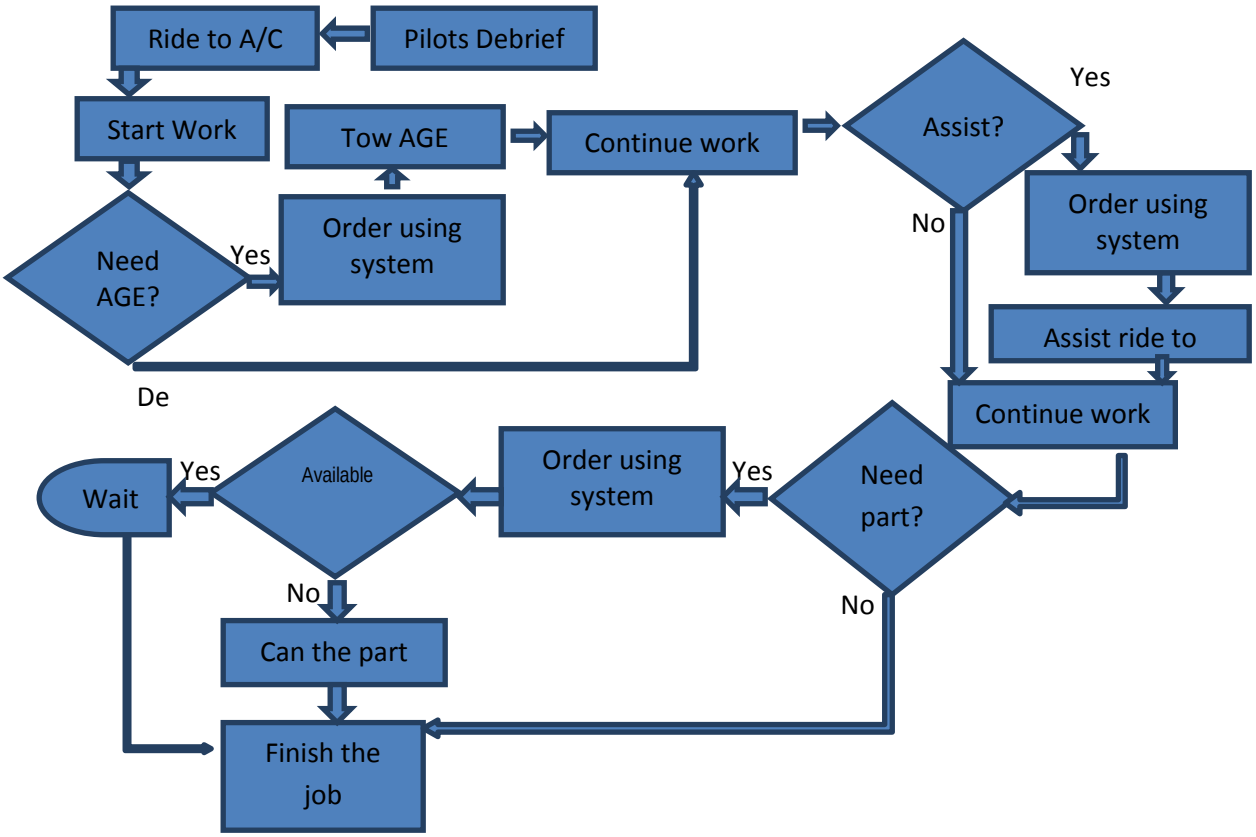


Figure 22. Recommended F-15 Maintenance Process

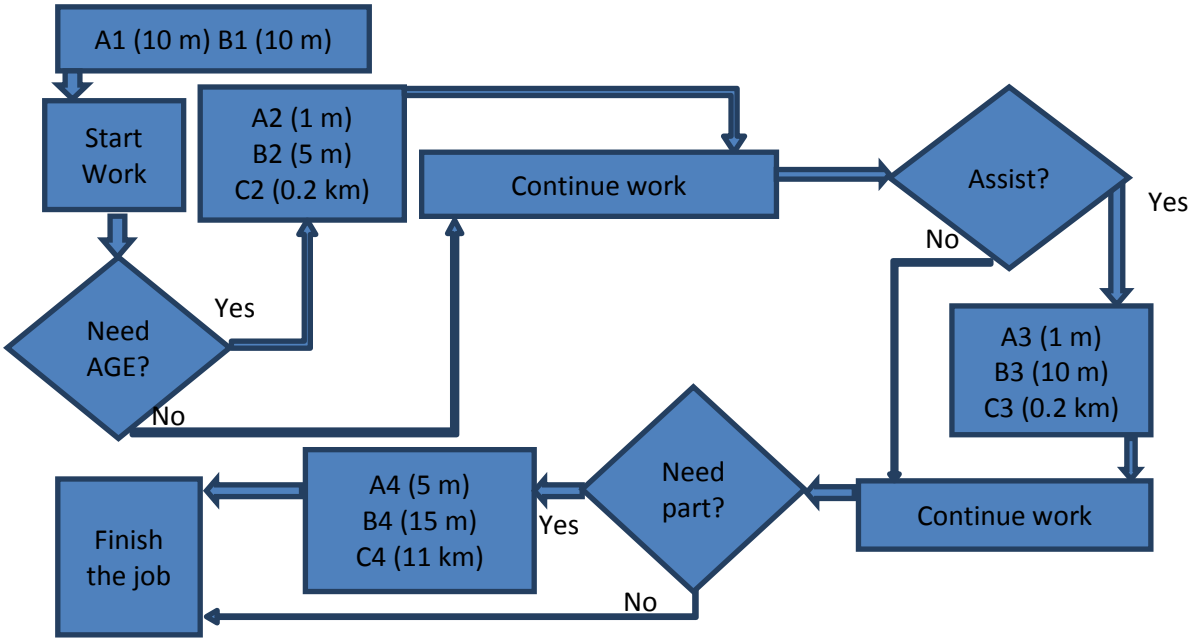


Figure 23. Recommended F-15 Maintenance Process in Numbers

- The cycle time for the F-15 maintenance process in the worst case for maintenance job that take 1 hour is: PW+200+140+280+320+ WT= 1110 minutes.
- The cycle time for the F-15 maintenance process in the standard case for maintenance job that take 1 hour is: PW+14+14+31+60+ WT= 219 minutes.
- The cycle time for the F-15 maintenance process in the improve case for maintenance job that take 1 hour is: 117minutes.
- Reduction in worst case = [(1050-57)/1050]*100= %94.6
- Reduction in standard case =[(159-57)/159]*100=%64.15

Table 6. Reduction in Communication For The New F-15 Maintenance Process.

Communication (Time)		
	Reduction from Standard %	Reduction from Worst %
A1	-	%80
A2	%75	%98.75
A-3a	%75	%98.75
A-3b	%83	%99
A4	%75	%93.75
Total	%59.1	%95

Table 7. Reduction in Time For The New F-15 Maintenance Process Compare to Current Process

waiting (Time)		
	Reduction from Standard %	Reduction from worst %
B1	%66.66	%83
B2	%50	%95.8
B-3a	-	%83
B-3b	%60	%94
B4	%62.5	%93.75
Total	%56.52	%92.4

Table 8. Reduction in Distance in The New F-15 Maintenance Process Compare to Current Process

Distance	
C1	% Reduction
C2	%87.5
C3	%97.5
C4	%90
Total	%92.85

V. Conclusion

This thesis explore applying Lean to F-15 maintenance process in Royal Saudi Air Force the results of this study suggests that by using lean, time can be saved in the maintenance process for the F-15, thus reducing the turnaround time needed to get thesis aircraft ready to fly

This thesis used lean to explore whether time can be saved in the F-15 maintenance process.

Lean made it possible to discover areas to improve a process. It made it possible to compare the results before and after. Lean also provided the possibility to use quantifiable metrics which made the process easier to understand and provided workers goals to achieve them.

One conclusion that should be taken into account is Lean has not been used at all in any F-15 maintenance process. Also, most of the individuals interviewed are not familiar with Lean. As the Royal Saudi Air Force continues trying to enhance the principles of total quality management and applying Lean the quality of the maintenance process are likely to improve.

While gathering information for the thesis, it became clear that communication between the Royal Saudi Air Force Head Quarters and the bases can be improved. The Head Quarters employees and some worker in bases have different understanding about Royal Saudi Air Force F-15 maintenance process regulations. Also commanders could

easily identify their customer but some subordinates could not. This indicates different understanding and perhaps a need for better communication.

All interviewed individuals agreed that the F-15 maintenance process can be improved. The majority of respondents agreed that there are unnecessary or wasteful steps that should be eliminated. Lean is designed to identify and eliminate these steps. Planning, sequencing and time management were given by the participants as possible solutions to the F-15 maintenance process and all of these proposals are used in Lean.

From collected information F-15 maintenance process in the Royal Saudi Air Force takes a lot of time to carry out on all of the aircraft. Excessive time spent in the process result in reducing the fight capability of the Royal Saudi Air Force. This also leads to excessive overtime work, even running into weekends for Aircraft Generation Flight staff. Such continual overtime causes the maintenance personnel to be under increased and unnecessary stress.

Lean considers waiting time and unnecessary or extra movement as waste that should be eliminated. From the gathered information, the F-15 maintenance process uses a lot of time in communication, waiting and distance. This thesis concludes all of wastes can be eliminated or reduced by applying Lean.

This thesis investigated the F-15 maintenance process for two specific cases; worse case and standard case. This results show the amount of improvement is possible for each of these cases. These investigations show results when applying Lean to the F-15 maintenance process in the Royal Saudi Air Force in table 9:

Table 9. Reduction in Process

	WORST CASE	STANDARD CASE
Communication	372 minutes (6.2 hours)	26 minutes
Waiting	610 minutes (10.6 hours)	65 minutes (1 hours)
Distance	19.6 Km	19.6 Km
Cycle Time	Extra 982 minutes (16.4 hours)	Extra 91 minutes (1.5 hours)

Extra times in cycle time are wasted in communication, waiting and distance. These loses are spent on fixing one aircraft only. Table 10 shows reduction Lean can make when applied to F-15 maintenance process.

Table 10. Reduction in Percentage

	WORST CASE REDUCTION	STANDARD CASE REDUCTION
Communication	95%	59%
Waiting	92%	56%
Distance	92%	92%
Cycle Time	94.6%	64%

This thesis indicates that, theoretically, that the reduction in the F-15 maintenance process metrics could be %94.6 for the worst case and %64 for the standard case. This is a huge improvement in the process for both cases. If these gains can be realized, it will save a lot of the Royal Saudi Air Force efforts in the F-15 maintenance process and increase the aircrafts' fight capability and readiness. In addition it should reduce work time and stress on the Aircraft Generation Flight staff.

Significance of This Research

This thesis is important to the Royal Saudi Air Force in several ways. It is good to recapitulate them to ensure their importance is not overlooked. One thing that makes this thesis so significant is that this thesis presents Lean as an idea for the Royal Saudi Air Force to adopt. Collected data show that participants had no clue (idea) about Lean. Applying this thesis in the field can actually result in increasing the readiness of the aircraft and their fight capability. In addition, application of Lean will reduce the daily efforts and wasted resources, power and equipment. Ultimately this will result in raising the morale of the Aircraft Generation Flight staff.

Limitation of Research

This study is only a theoretical study. It has not yet been applied on the Royal Saudi Air Force F-15 maintenance process. It should also be remembered that the researcher did not do the thesis and data collection in Saudi Arabia. Based on the Royal Saudi Air Force recommendations the number of individuals participating in the surveys and some of the questions were reduced from the original study plan.

Recommendations for Action

This thesis is theoretical research as mentioned earlier, so the first recommendation is to apply it on one of the Royal Saudi Air Force F-15 maintenance processes at one base. Full support and cooperation from all related wings and departments should be ensured to provide this trial an optimal chance of success. The program should be provided with the money, tools, equipment and manpower needed for

a fair evaluation. If the trial program succeeds, it should be generalized to include other bases and other types of aircraft that the Royal Saudi Air Force uses. There is no problem including United State Air Force employees who are expert in applying Lean to the maintenance process as consultants to assist and/or supervise the trial and continued expansion of the process to other systems.

Recommendation for Future Research

Future research can take this thesis as a basis and apply it to determine if the results of the trial are close to those projected in this thesis. Future research should also modify, extend, and improve on the assumptions and techniques made in this thesis or cover parts of Lean that this thesis did not address.

Appendix A

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OHIO

13 Jan 2014

MEMORANDUM FOR DR ALAN R. HEMINGER

FROM: Robert F. Mills, Ph.D.
AFIT IRB Exempt Determination Official
2950 Hobson Way
Wright-Patterson AFB, OH 45433-7765

SUBJECT: Approval for exemption request from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for *Research on Using Lean to Improve Royal Saudi Air Force F-15 Maintenance Process*.

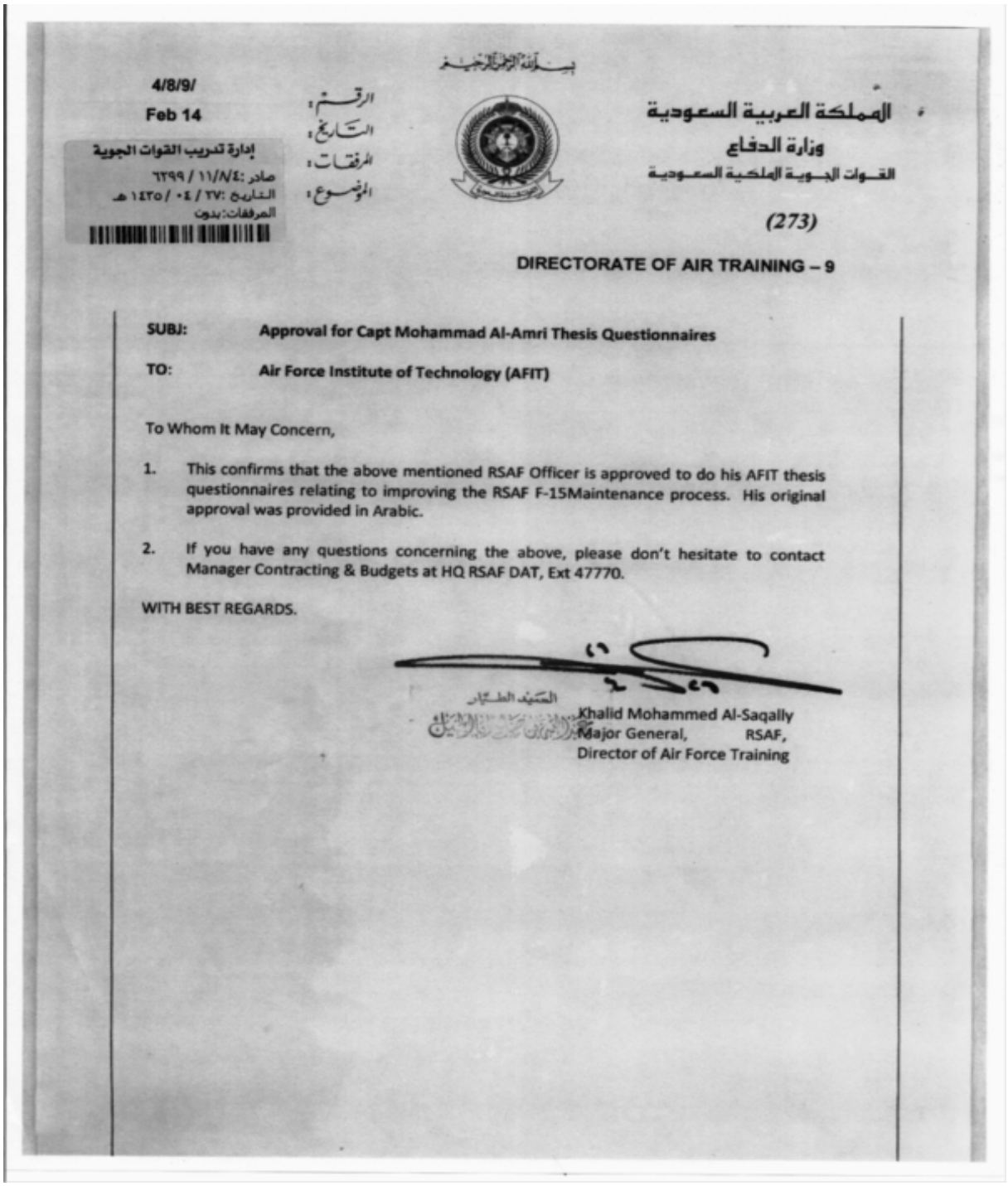
1. Your request was based on 32 CFR 219, 101(b)(2), Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

2. Your study qualifies for this exemption because you are not collecting sensitive data, which could reasonably damage the subjects' financial standing, employability, or reputation. The data being collected relates to the F-15 maintenance processes and does not include any personal information. Your plan includes ample and appropriate measures to safeguard any information collected, and your mitigation plan should such breech occur is adequate.

3. This determination pertains only to the Federal, Department of Defense, and Air Force regulations that govern the use of human subjects in research. Further, if a subject's future response reasonably places them at risk of criminal or civil liability or is damaging to their financial standing, employability, or reputation, you are required to file an adverse event report with the AFIT Research Review office immediately. Finally, because the study subjects are members of the Royal Saudi Air Force, the researcher must provide an approval letter from the Saudi government to gather the desired information.

ROBERT F. MILLS, Ph.D.
AFIT IRB Exempt Determination Official

Appendix B



بسم الله الرحمن الرحيم

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Feb 14

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القوات الجوية الملكية السعودية

(273)

DIRECTORATE OF AIR TRAINING – 9

SUBJ: **Approval for Capt Mohammad Al-Amri Thesis Questionnaires**

TO: **Air Force Institute of Technology (AFIT)**

To Whom It May Concern,

1. This confirms that the above mentioned RSAF Officer is approved to do his AFIT thesis questionnaires relating to improving the RSAF F-15Maintenance process. His original approval was provided in Arabic.

2. If you have any questions concerning the above, please don't hesitate to contact Manager Contracting & Budgets at HQ RSAF DAT, Ext 47770.

WITH BEST REGARDS.

العقيد الطيار
Khalid Mohammed Al-Saqally
Major General, RSAF,
Director of Air Force Training

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Vita

Captain Mohammad Alamri from Royal Saudi Air Force. Studied and graduated from Alabna schools in Riyadh the capital of Saudi Arabia. Finished his Bachelor degree in Mechanical Engineering in 2007 from King Saud University.

First assignment for Captain Alamri was in King Abdul-Aziz Air base as an F-15 maintenance officer. He has been stationed in many other places around Saudi Arabia for TDY and job courses. In September 2012 he entered the Graduate School of Engineering and Management, Air Force Institute of Technology.

REPORT DOCUMENTATION PAGE

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5b. GRANT NUMBER

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14. ABSTRACT
The thesis was about applying lean to the F-15 maintenance process in Royal Saudi Air Force. The researcher collected the data by using several questionnaires. Researcher used external lean expert recommendation to avoid bias, the F-15 maintenance process improved theoretically.

15. SUBJECT TERMS
LEAN, AIRCRAFT MAINTENANCE, F-15 MAINTENANCE PROCESS, MAINTENANCE

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Alan Heminger (AFIT/ENV)
U	U	U	UU	96	19b. TELEPHONE NUMBER *(Include area code)* (937)785-3636, x 7405 U (Alan.Heminger@afit.edu)